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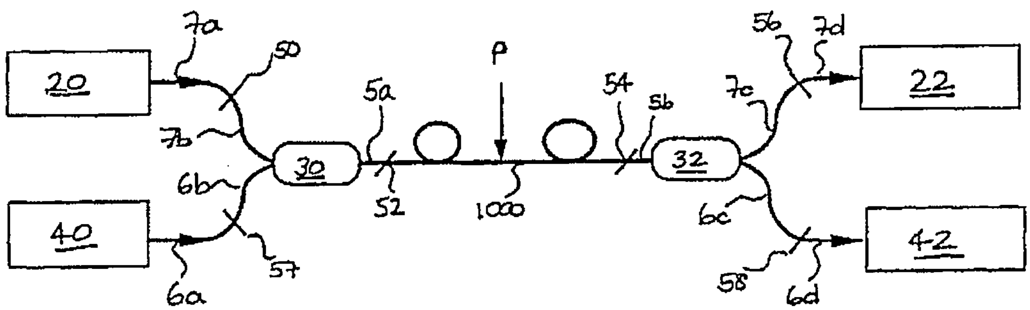

(57) Abstract

An optical waveguide system for securing live fibres against tampering and tapping off of data in optical fibre communication links is disclosed. The communication link includes a waveguide (1000) which extends from one location to another for transmitting a data signal. A data transmitter (20) launches the data signal into the fibre (1000) and a data receiver (22) receives the data signal. A sensing signal transmitter (40) launches a sensing signal into the fibre (1000) and a sensing signal receiver (42) receives the sensing signal for the fibre (1000). The transmitters (20 and 40) are coupled to the fibre (1000) by wavelengths multiplexing/demultiplexing coupler (30) via input arms (76 and 66) of the coupler (30). The signals are transferred to the receivers (22 and 42) by a further wavelength multiplexing/demultiplexing coupler (32) via output arms (7c and 6c). The couplers (30 and 32) ensure that the signals are combined with minimum power loss and are separated for transmission to the detectors also with minimum power loss and with substantially all of the data signal being transmitted to the receiver (22) and all the sensing signal being transmitted to the receiver (42).

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INTRINSIC SECURING OF FIBRE OPTIC COMMUNICATION LINKS

FIELD OF THE INVENTION

This invention relates to optical waveguide systems formed for securing live-fibres against tampering and tapping-off of data in optical fibre communication links.

ART BACKGROUND

Optical devices are commonly used in industry and science and include laser cavities, waveguides, lenses, filters and other optical elements and their combinations. Such optical devices are used in a variety of instruments and installations.

Photonics technology has revolutionised the communications and sensor fields. This is mainly due to the rapid development of optical and opto-electronic devices. A wide variety of glass materials, material-dopants and waveguide structures are available and this provisional specification relates to optical waveguide systems formed for securing live-fibres against tampering and tapping-off of data in optical fibre communication links.

Communications using an optical fibre have a number of attractive features and advantages over conventional communication means. These advantages include the following:

- Greater bandwidth and capacity
- Electrical isolation
- Low error rate
- Immunity to external influences
- Immunity to interference and crosstalk
- Signal security
- Ruggedness and flexibility
- Potential low cost

The high expectations of optical fibres as information carriers in communication systems have been justified by

their performance over the past two decades. Due to their high bandwidth, low attenuation and mechanical properties, each fibre is capable of replacing over 1000 copper wires in telecommunication systems. With these characteristics it is no surprise that optical fibres have become the most affordable and efficient medium available in the field of telecommunications. Furthermore, the increased capacity, ease of system expandability, and reduced installation, operation and maintenance costs of the technology, is also making a strong impact in industry, replacing many of the traditional communication systems.

The use of optical fibres as the main backbone of most communication systems has meant that large amounts of information can be efficiently and cost effectively transferred from point to point. Modern fibre optic communications networks deploy optical fibre over millions of kilometres worldwide, carrying important and confidential information of a government, military, financial and personal nature. Although it was initially thought that optical fibre transmission would be inherently secure, we now know that it is relatively easy to 'tap' information out of an optical fibre with negligible interference to the optical signal. It has became obvious that in order to extract 100% of the information which is transmitted via the fibre optic cable, it is sufficient to bend the fibre only slightly or clamp onto it at any point along its length and photons of light will leak into the receiver of the intruder. Even when only 0.1 dB (2%) of the signal is leaking, it will contain all of the information being transmitted in each photon. The user at the other end will never know that his information has been tampered with since they will experience no apparent interference with their communications. A loss of 0.1 dB represents the lowest practical detectable optical loss in a fibre system by modern test equipment and network management systems. The

same technique could also be used in order to introduce false information or to corrupt existing information flow. This can have serious security implications for users of optical fibre communication systems, especially telecommunications carriers, banks, brokerage houses, treasuries, defence organisations, government organisations, embassies and corporations, to name a few. All these information carriers and users are totally vulnerable to intrusion, tampering and tapping-off of their data. This vulnerability issue has not been publicly raised to-date because suppliers and users have failed to understand the potential threat and because there have been no effective solutions. Most people today still believe that optical fibres are the most secure means of communications, which is not actually true.

Until recently, the only available techniques of protection against intrusion of fibre optic telecommunications involved the use of:

- encryption of the information being transmitted;
- physical security systems based on physical barriers (ie., thicker coatings on the fibres, thicker and harder protective jackets on the cables and housing the cables in conduits); and
- static or slowly varying measurements using optical time domain reflectometers (OTDRs) to detect fibre fracture, sharp bends, fibre attenuation or connector losses.

Encryption techniques can be very costly, they often slow the system speed considerably/unacceptably and are not ever totally secure.

Physical security measures are not truly effective in uncovering tampering with a fibre optic communications link since they require the fibre to be cut, fractured or severely bent before the problem can be detected.

OTDRs are ineffective at detecting dynamic or transient disturbances to a fibre cable. In addition, their functionality limits them to measuring only optical losses, but with relatively low sensitivity, thus they are practically limited to detecting significant and permanent or very slowly changing (and often destructive) effects on the cable.

With millions of kilometres of optical fibre deployed worldwide, the monitoring of fibre cable tampering, integrity and the prediction of the onset of failure and damage is critical to the security and reliability of fibre communication systems. Most current techniques for monitoring fibre optic cable tampering or integrity are based on static or very-slowly varying measurements using an OTDR. However, it would be a technological breakthrough to be able to obtain real-time, quasi-static and dynamic information about non-destructive disturbances anywhere along the fibre cable. This would have the further advantage of monitoring any disturbance to the cable and any structure or material near the cable or to which the cable is attached. Such a capability should also enable simultaneous, real-time fibre optic communications and sensing applications such as structural integrity monitoring, leak detection, ground monitoring, machine condition monitoring and intrusion detection.

This is possible because optical fibres can be more than mere signal carriers. Light that is launched into and confined to the fibre core propagates along the length of the fibre unperturbed unless acted upon by an external influence. Specialised sensing instrumentation may be configured such that any disturbance of the fibre which alters some of the characteristics of the guided light (ie., amplitude, phase, wavelength, polarisation, modal distribution and time-of-flight) can be monitored, and related to the magnitude of the disturbing influence.

Such modulation of the light makes possible the measurement of a wide range of events and conditions, including:

- Strain/residual strain
- displacement
- damage
- cracking
- vibration/frequency
- deformation
- impact
- acoustic emission
- liquid levels
- pressure
- temperature
- load

Fibre optic sensor technology has progressed at a rapid pace over the last decade. Different configurations of fibre sensing devices have been developed for monitoring specific parameters, each differing by the principle of light modulation. Fibre optic sensors may be intrinsic or extrinsic, depending on whether the fibre is the sensing element or the information carrier, respectively. They are designated "point" sensors when the sensing gauge length is localised to discrete regions. If the sensor is capable of sensing a measurand field continuously over its entire length, it is known as a "distributed" sensor; "quasi-distributed" sensors utilise point sensors at various locations along the fibre length. Fibre optic sensors can be transmissive or can be used in a reflective configuration by mirroring the fibre end-face.

Hence, fibre optic sensors are actually a class of sensing device. They are not limited to a single configuration and operation unlike many conventional sensors such as electrical strain gauges and piezoelectric transducers. Consequently, fibres are now replacing the role of

conventional electrical devices in sensing applications to the extent where we are now seeing a multitude of sensing techniques and applications being explored for practical gain.

However, to-date most fibre optic sensor systems are based on point sensing devices, thus requiring a large number of sensors to cover a large area or long length of interest. The subsequent cost and complexity of such systems is most often restrictive or impractical.

Very few distributed techniques have been developed and are commercially available. Of those that have been developed, most monitor only temperature and fewer still have the capability to actually locate the region or position of the sensed parameter or disturbance along the fibre length; they simply detect, alert and sometimes quantify that an event has occurred. Furthermore, many of these techniques are often limited to monitoring static or very slowly varying parameters due to the requirement of measuring and averaging the time-of-flight of very narrow, low power back-reflected optical pulses (most are based on OTDR principles).

However, it would be a significant advance to be able to also obtain real-time, quasi-static and dynamic information about any form of disturbance to the optical fibre and their location, particularly transient events which are too quickly occurring to detect with OTDR techniques. This can be achieved by combining a distributed sensing technique incapable of locating the events with a compatible technique that is capable of locating the events. Such a capability would enable truly distributed sensing applications such as fibre cable tampering or third-party interference detection, as well as offering the further advantage of monitoring any structure or material near the fibre or to which the fibre

is attached (ie., structural integrity monitoring, pipeline leak detection, ground monitoring, machine condition monitoring and intrusion detection of high security areas).

Our International application no. PCT/AU95/00568 discloses fibre optic distributed vibration sensing technology. The sensing technique was based on a unique fibre optic modalmetric sensor configuration. This technology overcomes the inherent weaknesses of most multimode fibre optic sensors, offering truly localised, mechanically stable and linear sensing. The sensing is achieved by using a modalmetric interference effect, which is based on the modulation of the modal distribution (effectively changing the intensity) in a multimode optical fibre by external perturbations. In this method, the sensor response is a direct function of the disturbance on the sensitive portion of the fibre. The disturbance may be in the form of physical movement (ie., compression (radially or axially), elongation, twisting, vibration, etc.) or microphonic effects (ie., travelling stress waves or acoustic emissions). The ability to vary the sensing length to fit specific applications is a major and unique advantage of this technology. This is particularly relevant if long sensing lengths are required, as is the case when combining the sensing technique with fibre optic communications. The only limitation imposed on the sensing length is in the optical power budget of the system. Therefore, if a longer sensing length is desired a higher power laser is required.

The system of this international application provides a simple, effective and inexpensive technique to detect and characterise both small and large disturbances on any optical fibre cable, anywhere along its entire length, and in real-time. This offers the capability of simultaneously utilising a fibre optic communications

cable as a tampering-alert, intrusion-alert or integrity-testing sensing cable, thus providing continuous, real-time monitoring of the fibre cable and any structure near the cable (ie., ground, tunnels, ducts, pipes, buildings, equipment, vessels, etc.).

One of the key features of the technology is its configuration-flexibility since it is wavelength independent. This makes it possible to use with any type of optical fibre, thus it can be simultaneously retrofitted and integrated into any existing fibre optic communications cable, without requiring the installation and cost of a new cable.

Subsequently, this technology was to be capable to be operated simultaneously with a communications system within the same optical fibre or cable, adding significant value to any communications system in regard to security and enabling easy integration of the distributed sensing technology into an existing fibre optic network. To achieve this, they demonstrated a wavelength multiplexed optical fibre system which can be used in both standard singlemode (9/125 µm) and standard multimode (62.5/125 µm) optical fibre systems for simultaneous communications and sensing.

Figure (1) illustrates the configuration used for the demonstration of a simultaneous fibre optic communications and sensing system. The system configuration consisted of the fibre link 1, either single or multi moded, with standard 3 dB (50% splitting ratio), 2x2 fibre couplers 3a, 3b at each end to allow for the multiplexing and demultiplexing of the two wavelengths at the transmitter and receiver ends, respectively. The choice of sensing wavelength was important as the responsivity of the InGaAs detector 2b in the communication channel needed to be negligible at the sensing wavelength. Thus, the

communication channel 2a was chosen to operate at a wavelength of 1300 nm whilst the sensing channel 4a was chosen to operate at either 633 nm or 850 nm. This ensured that inter-channel crosstalk was negligible, as the Si 4b detector utilised in the sensing channel would not respond to the 1300 nm communications signal.

Figure (2) illustrates the results from the sensing arrangement shown in Figure (1) when a vibrational disturbance was applied to a short section of the fibre link. A vibrational disturbance was applied to a small section (5 cm) of the fibre link using a cantilever beam arrangement. The fibre was simply taped longitudinally along the beam length. A typical sensor response is shown in Figure (2a) for a 28 km singlemode (SM) link and in Figure (2c) for a 53 km multimode (MM) fibre link. As can be seen, very good signal quality was obtained. In addition, the Fast Fourier Transforms (FFTs) (Figures 2b and 2d) clearly identify the natural frequency of the beam to be ~18 Hz with both links.

Simultaneous, non-interfering communication and sensing was thus successfully demonstrated on a SM optical fibre link with a communications data rate of 50 Mb/s as well as a 500MHz analog communications channel bandwidth system using a sensing wavelength of 633 nm and 850 nm, respectively.

While this technology had proven itself effective for securing fibre optic communications cables it still had one significant limitation that would limit its commercial attractiveness; it was not capable of pin-pointing the location of the disturbance to the fibre. In order to overcome this major limitation, our International application no. PCT/AU99/01028 discloses a compatible methodology and technology for locating disturbances in fibre optic sensing systems. The technique relies on the

measurement of the time delay or difference between transmissive counter-propagating optical signals affected by the same event in a two-ended fibre arrangement. In this novel arrangement, as illustrated in Figure (3), continuous-wave (CW) optical signals S and S1 are simultaneously launched, preferably from a single light source, into opposite ends of a sensing optical fibre 1 or set of fibres and simultaneously detected by synchronised photodetectors. Pulsing of the optical signal is not necessary, although it may be employed in some arrangements. Any sensed parameter P which acts to alter the counter-propagating signals will effect both signals in the same manner, but because the effected counter-propagating signals must each continue travelling the remainder of the fibre length to their respective photodetectors there is a resultant time delay or time difference between the detected signals. The time delay is directly proportional to the location of the sensed event along the fibre length. Therefore, if the time delay or difference is detected and measured, the location of the event can be determined. At the same time, if a compatible sensing mechanism is being employed the sensed event can be quantified and/or identified (ie., strain, vibration, acoustic emission, temperature transients, etc.). In addition, non-sensitive fibre optic delay lines L may be connected to the sensing fibre at either or both ends in order to add additional delay between the transmissive counter-propagating signals and to provide insensitive lead fibres.

This technique enables dynamic and transient events to be located in virtually any distributed fibre optic sensing system, and its transmissive counter-propagating technique does not possess the limitations and complexities of OTDR principles.

The system has the following advantages:

- Operates on virtually any existing type of transmissive distributed fibre optic sensor, enabling dynamic and transient events to be detected, quantified, characterised and located anywhere along the length of the optical fibre.
- Operates in a transmissive configuration, thus delivering the entire optical signal and power back to the detector and not requiring signal averaging.
- Determines the location of events via the time delay measured between counter-propagating optical signals effected by the same disturbance. The spatial resolution is, therefore, limited and set by the speed of the data acquisition system.
- Does not require laser pulsing, although it is capable of operating with pulsed techniques.

With the two above-mentioned advances , there has been proposed one possible configuration for monitoring and locating disturbances to a fibre optic communications cable by utilising a non-active ("dark") fibre in the cable, as illustrated in Figure (4). However, feedback from industry has also emphasised the desire to monitor active ("live") fibres in certain circumstances.

A simple solution to this requirement would be to utilise the wavelength multiplexing method illustrated in Figure (1). However, the use of 3 dB couplers imposes an additional minimum optical loss of 6 dB, which could severely impact the optical power budget of most communications systems. Ultimately, it would be desirable to implement the modalmetric sensing and the locating techniques in such an optical arrangement that would minimise the optical power losses to a communications system. If, likewise, the arrangement also minimised the optical power losses to the sensing system, then it would be possible to design and configure a communications node or junction by-pass arrangement for the sensing signal in

Figure 7 is a view showing a general embodiment of the invention for a two-ended counter-propagating sensing and locating arrangement operating over a singlemode optical fibre telecommunication link;

Figure 8 is a view showing a general embodiment of the invention for a single-ended counter-propagating sensing and locating arrangement operating over a singlemode optical fibre telecommunication link;

Figure 9 is a view showing another general embodiment of the invention for a transmissive sensing arrangement operating over a multimode optical fibre telecommunication link;

Figure 10 is a view showing another general embodiment of the invention for a reflective sensing arrangement operating over a multimode optical fibre telecommunication link;

Figure 11 is a view showing another general embodiment of the invention for a two-ended counter-propagating sensing and locating arrangement operating over a multimode optical fibre telecommunication link;

Figure 12 is a view showing another general embodiment of the invention for a single-ended counter-propagating sensing and locating arrangement operating over a multimode optical fibre telecommunication link;

Figure 13 is a view showing a further general embodiment of the invention, utilising a plurality of WDM couplers in a singlemode optical fibre, three-node, point-to-point network arrangement, forming a junction by-pass arrangement for the sensing signal in order to extend the sensing fibre length beyond one communication node;

Figure 14 is a view showing a further general embodiment of the invention, utilising a plurality of WDM couplers in a multimode optical fibre, three-node, point-to-point network, forming a junction by-pass arrangement for the sensing signal in order to extend the sensing fibre length beyond one communication node;

order to extend the sensing fibre length beyond one communication node. This would be particularly useful for ring topology networks.

BRIEF SUMMARY OF THE INVENTION

The object of the present invention is to provide optical waveguide systems formed for securing live-fibres against tampering and tapping-off of data in optical fibre communication links, while minimising optical power losses to both the communications and sensing signals.

The present invention provides an optical waveguide communication link, including;

a waveguide for conveying signals from one location to another location;

a data transmitter for launching a data signal at a first wavelength into the waveguide;

a data receiver for receiving the data signal from the waveguide;

a sensing signal transmitter for launching a sensing signal at a second wavelength different to the first wavelength, into the waveguide;

a sensing signal detector for detecting the sensing signal after the sensing signal has travelled through the waveguide; and

signal splitting means between the waveguide and the data receiver and the sensing signal detector so that the signal at the first wavelength is separated from the sensing signal at the second wavelength by the signal splitting means so that substantially all of the data signal without significant loss and without any significant component of the sensing signal is directed to the data receiver, and substantially all of the sensing signal without any significant loss and without any significant component of the data signal is directed to the sensing signal detector.

Thus, according to the invention both the sensing signal and the communication signal can be launched into a single waveguide and transmitted along the waveguide whereupon the system separates the individual wavelength components of the sensing signal and the data signal for transmission to their respective data receiver and signal sensing detector so that if both signals are received without substantial contamination by the other signal and with minimum optical power loses. Thus, sensitivity of the transmitted data signals and sensing signals is greatly enhanced thereby enabling proper communication of data and also proper sensing of any attempt to interfere with the waveguide to tap off data from the waveguide.

In the preferred embodiment of the invention the signal splitting means comprises a wavelength multiplexing/demultiplexing waveguide coupler.

According to the preferred embodiment of the invention the data signal from the waveguide and the sensing signal from the sensing signal transmitter are received by a wavelength multiplexing/demultiplexing coupler to combine the signals for transmission along the waveguide.

The utilisation of wavelength multiplexing/demultiplexing (WDM) waveguide devices to combine and separate the individual wavelength components of the communications and sensing signals in the same optical fibre, minimises the optical power losses. For example, while a typical 2x2 coupler splits the transmitted light in either direction into two roughly-equal signals (50/50% power split), a WDM coupler efficiently taps off or inserts specific wavelengths with considerably less loss (typically ~10%).

In one embodiment of the invention the sensing signal transmitter and sensing signal detector are at the said one location and said another location respectively.

However, in other embodiments the sensing signal transmitter and the sensing signal detector are located both at one or the other of the said one location or the another location and wherein a reflector is provided for reflecting the sensing signal back through the waveguide after separation of the sensing signal from the data signal by the signal splitting means.

Preferably the reflector comprises a reflective mirror.

In one embodiment the sensing signal transmitter comprises a counter-propagating sensing signal transmitter for launching counter-propagating sensing signals into the waveguide and travel in opposite directions through the waveguide to enable the position of any disturbance to the waveguide to be determined by the difference between the time a perturbing sensing event is detected in both counter-current sensing signals.

Preferably processing means is provided for processing the sensing signal to determine a change in parameter within the signal to identify a disturbance to the waveguide indicative of tampering with the waveguide.

In one embodiment of the invention the communication link includes a plurality of communication nodes, at least one of the nodes including a said data transmitter, a second node including a said data receiver and a further said data transmitter, and a third node including at least a further said data receiver, the waveguide interconnecting each of the nodes so that the sensing signal passes through the waveguide from the first node to the third node.

In a still further embodiment the waveguide forms a continuous loop including a plurality of communication nodes arranged along the loop, at least one of the loop having a said sensing signal transmitter and a said sensing signal detector.

Preferably a said signal combining means is provided for directing a data signal from a data transmitter at one of the nodes, to a said data receiver at another of the nodes.

The present invention may also be said to reside in an optical waveguide communication link including;

a waveguide for conveying signals from one location to another location;

a data transmitter for launching a data signal into the waveguide;

a first wavelength multiplexing/demultiplexing waveguide device coupled to the waveguide, the waveguide device having a first output arm and a second output arm;

a sensing signal transmitter for launching sensing signal having a wavelength different to the wavelength of the data signal into the waveguide for transmission with the data signal along the waveguide;

a data receiver coupled to the first output arm for receiving the data signal from the waveguide device;

a sensing signal detector coupled to the second output arm for receiving a sensing signal from the waveguide device.

Preferably the waveguide device comprises a wavelength multiplexing/demultiplexing coupler.

Preferably a second waveguide device is coupled to the waveguide remote from the first waveguide device, the second waveguide device having a first input arm and a

second input arm, the first input arm being coupled to the data transmitter and the second input arm being coupled to the sensing signal transmitter so that the data signal and the sensing signal are transmitted to the second waveguide device for launching into the waveguide.

Preferably the second waveguide device is coupled to the waveguide by an output arm which receives both the data signal and sensing signal from the second waveguide device.

Preferably the first waveguide device is coupled to the waveguide by an input arm so that both the sensing signal and data signal are transmitted through the input arm to the first waveguide device.

Preferably the first waveguide device comprises a first wavelength multiplexing/demultiplexing (WDM) coupler having the input arm and the first and second output arms.

Preferably the second waveguide device comprises a second wavelength multiplexing/demultiplexing (WDM) coupler having the first input arm, the second input arm and the output arm.

Preferably the waveguide comprises an optical fibre. The optical fibre may be a single mode fibre or a multimode fibre.

In one embodiment the second output arm of the first WDM coupler is connected to a reflector to reflect the sensing signal back into the waveguide through the WDM coupler, and the second input arm of the second WDM coupler is connected to an ancillary coupler, the ancillary coupler having first and second ancillary input arms, the first ancillary input arm being connected to the sensing signal

transmitter and the second ancillary input arm being connected to the sensing signal detector so that the sensing signal reflected back from the reflector passes through the first WDM coupler, and through the second WDM coupler to the second input arm, through the ancillary coupler to the second ancillary arm and then to the sensing signal detector.

The preferred embodiment of the present invention provides a waveguide system for securing live-fibres against tampering and tapping-off of data in optical fibre communication links, which may include:

- providing a sensing system light source operating at a wavelength different to the communications system light source;
- providing a wavelength multiplexing waveguide light splitter or coupler (single or multi moded) which efficiently combines the sensing and communications signals into one waveguide;
- providing a silica waveguide (single or multi moded) for receiving light from the wavelength multiplexing waveguide light splitter or coupler, the silica waveguide being capable of transmitting the sensing and communications signals in the required manner along its length, but particularly such that the sensing wavelength and the waveguide characteristics satisfy the requirements of the modalmetric sensing and locating techniques described earlier while unaffecting the communications signal;
- providing a wavelength demultiplexing waveguide light splitter or coupler (single or multi moded) which efficiently splits or separates the sensing and communications signals into two output waveguide ports while minimising optical power losses to both the communications and sensing signals; and
- providing detector means for detecting the sensing signal and, if required, the counter-propagating sensing

optical signals effected by the same parameter and for determining the time delay or difference between the signals in order to determine the location of the sensed event.

Preferably further silica waveguides are connected to the first silica waveguide at either or both ends in order to provide insensitive lead waveguides and, if applicable, to add additional delay between the transmissive counter-propagating signals.

In another embodiment the sensing wavelength output port of the wavelength demultiplexing waveguide coupler is terminated with a reflective mirror so as to operate the sensing technique in a reflective mode. Similarly, a mirrored waveguide could be connected to the sensing wavelength output port of the wavelength demultiplexing waveguide coupler.

If only the sensing technique is utilised, preferably the detector means comprises:

- a photodetector for receiving the transmitted or reflected radiation from the sensing signal in the silica waveguide; and
- processing means for receiving signals from the photodetector and analysing the signals in order to register the sensed events.

If the locating technique is utilised as well as the sensing technique, preferably the detector means comprises:

- first and second photodetectors for simultaneously receiving the radiation from the counter-propagating signals in the silica waveguide; and
- processing means for receiving signals from the first and second photodetectors and analysing the signals in order to register the sensed events and determining the

time delay or difference between the counter-propagating signals effected from the same disturbance, thus determining the location of the sensed events.

In a preferred embodiment the silica waveguide is a multimoded fibre at the sensing wavelength and the lead waveguides are singlemode fibres at the sensing wavelength.

In a preferred embodiment, but without limitation, the distributed sensing technique is based on a modalmetric technique utilising the fusion splicing of insensitive singlemode fibre to sensitive multimode fibre.

In another preferred embodiment, the transmissive counter-propagating signal method for locating events is employed, and suitable optical devices are employed at one or both ends of the system to detect the signals.

In a preferred embodiment the wavelength multiplexing/demultiplexing (WDM) couplers are 2x1 WDM couplers. In other embodiments they may be any suitable multi-port device, such as 2x2, 3x1, 4x2, etc.

In a preferred embodiment all the optical fibres and fibre devices are connected by fusion splices. In other embodiments the optical fibres and fibre devices may be connected by any suitable or appropriate technique, such as mechanical splices, connectorised leads and through-adaptors, etc.

In other embodiments the WDM couplers may be replaced with alternate wavelength filtering, conditioning, combining, splitting or directing devices.

In other embodiments a plurality of WDM couplers are utilised in a ring topology network, forming junction by-

pass arrangements for the sensing signal in order to extend the sensing fibre length beyond one communication node.

Preferably the waveguide comprises at least one optical fibre and/or at least one optical fibre device. In some embodiments of the invention the waveguide may merely comprise an optical fibre without any additional elements. However, the optical fibre can include passive or active elements along its length. Furthermore, the optical fibre can include sensing elements along its length and those sensing elements can comprise devices which will respond to a change in the desired parameter in the environment of application and influence the properties and characteristics of the sensing electromagnetic radiation propagating in the waveguide to thereby provide an indication of the change in the parameter.

Preferably any suitable CW or pulsed single or multiple wavelength source or plurality of sources may be employed. In a preferred embodiment, without limitation, a CW or pulsed coherent laser diode is utilised to supply the optical signal. In an alternate arrangement, multiple light sources, of the same or varying wavelengths, may be used to generate the sensing signal or a plurality of sensing signals. In other embodiments it is possible to combine the sensing and data transmitters into one transmitting device.

The preferred embodiments of the present invention offer the potential to utilise all-fibre, low-cost optical devices in conjunction with laser diodes, light emitting diodes, photodetectors, couplers, WDM couplers, isolators and filters.

In the preferred embodiments of the present invention any suitable light source, coupler and photodetector

arrangement may be used with the sensor and locating systems. In a preferred embodiment, the required optical properties of the light source are such that light may be launched into and propagated in the singlemode waveguide. For localisation, the light propagated in a singlemode fibre must remain singlemoded during the entire period of travel in the singlemode fibre. Once the light is launched into the multimode fibre from the singlemode fibre, several modes may be excited and the multimoded fibre will be sensitive to various parameters. Once the light is launched back into the singlemode fibre from the multimode fibre, only a single mode is supported and travels to the optical components of the system. Lead-in/lead-out fibre desensitisation and sensor localisation is achieved in this manner. In practical applications, the singlemode fibre should be made sufficiently long to attenuate all cladding modes in order to improve the signal-to-noise ratio. This preferred embodiment applies for both directions of travel of the transmissive counter-propagating optical signals.

Utilisation of properties and characteristics of the electromagnetic radiation propagating in the waveguide sensor enables monitoring to take place in a non-destructive manner. Thus, the sensor is not necessarily damaged, fractured or destroyed in order to monitor and locate the desired parameter.

In another embodiment the multimoded fibre is replaced by two single moded fibres and couplers and the sensing occurs on a phase interferometric principle

In the method, according to the preferred embodiment of the invention, electromagnetic radiation at the sensing wavelength is launched into an optical waveguide (single or multi moded), such as an optical fibre, from a light source, such as a pigtailed laser diode, fibre laser or

light emitting diode, and propagates along the optical waveguide. The optical waveguide is fusion spliced, or otherwise connected (temporarily or permanently), to one input arm of an optical waveguide wavelength multiplexing light splitter or coupler (single or multi moded) and when the electromagnetic radiation reaches the coupler the electromagnetic radiation can branch out into the output waveguide arm of the coupler. Simultaneously, electromagnetic radiation at the communications wavelength is launched into another optical waveguide (single or multi moded), such as an optical fibre, from a light source, such as a pigtailed laser diode, fibre laser or light emitting diode, and propagates along the optical waveguide. The optical waveguide is fusion spliced, or otherwise connected (temporarily or permanently), to the second input arm of the wavelength multiplexing coupler and when the electromagnetic radiation reaches the coupler the electromagnetic radiation can likewise branch out into the same output waveguide arm of the coupler as the sensing signal. Thus, the wavelength multiplexing coupler efficiently combines both the sensing and communications signals into a single output waveguide arm. If a wavelength multiplexing coupler with two output arms is used then the unused arm is fractured or otherwise terminated to avoid back-reflections. The output arm of the wavelength multiplexing coupler is fusion spliced, or otherwise connected (temporarily or permanently), directly to the main waveguide transmission link (single or multi moded for the communications signal and multimoded for the sensing signal). Both the communications and sensing signals propagate along the entire length of the waveguide, without interfering with one another, until they reach the opposite end of the link. The main waveguide is then fusion spliced, or otherwise connected (temporarily or permanently), to the input arm of a wavelength demultiplexing coupler and when the signals reach the coupler they are efficiently separated and

branched out into two separate output arms of the coupler. The output arms of the wavelength demultiplexing coupler are then terminated at appropriate photodetectors. Appropriate electronics, signal processing schemes and algorithms process the signals from the photodetectors to obtain the desired information.

In a preferred embodiment the WDM couplers are 2x1 WDM couplers. In other embodiments they may be any suitable multi-port device, such as 2x2, 3x1, 4x2, etc.

In other embodiments a plurality of WDM couplers are utilised to form junction by-pass arrangements for the sensing signal in order to extend the sensing fibre length beyond one communication node.

In a preferred embodiment all the optical fibres and fibre devices are connected by fusion splices. In another embodiment the optical fibres and fibre devices are connected by any suitable or appropriate technique, such as mechanical splices, connectorised leads and through-adaptors, etc.

In another embodiment the sensing wavelength output port of the WDM coupler is terminated with a reflective mirror so as to operate the sensing technique in a reflective mode. Similarly, a mirrored fibre could be connected to the output port of the WDM coupler.

In another embodiment, the transmissive counter-propagating signal method for locating events is employed, and suitable optical devices are employed at one or both ends of the system to detect the signals.

In other embodiments the WDM couplers may be replaced with alternate wavelength filtering, conditioning, combining, splitting or directing devices.

Preferably the instrument optical and electronic arrangements will utilise noise minimisation techniques.

Preferably, all the optical and electrical components will be located in a single instrument control box, with individual optical fibre input/output ports.

Optical devices, electro-optic devices, acousto-optic devices, magneto-optic devices and/or integrated optical devices may also be utilised in the system.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present invention will be further illustrated, by way of example, with reference to the following drawings in which:

Figure 1 shows an integrated fibre optic sensing and communications system, utilising the modalmetric sensing technique;

Figure 2a, Figure 2b, Figure 2c and Figure 2d are graphs showing the results from the sensing arrangement shown in Figure 1 when a vibrational disturbance was applied to a short section of the fibre link;

Figure 3 shows the basic principle of the waveguide transmissive counter-propagating signal method for locating events in fibre optic sensing systems;

Figure 4 shows a combined fibre optic sensing and communications arrangement, utilising a modalmetric sensing technique and the ability to locate disturbances formed by the method of Figure 3;

Figure 5 is a view showing a general embodiment of the present invention for a transmissive sensing arrangement operating over a singlemode optical fibre telecommunication link;

Figure 6 is a view showing a general embodiment of the invention for a reflective sensing arrangement operating over a singlemode optical fibre telecommunication link;

Figure 15 is a view showing yet another general embodiment of the invention, utilising a transmissive sensing arrangement and a plurality of WDM couplers in an optical fibre ring topology network, forming several junction by-pass arrangements for the sensing signal in order to extend the overall sensing fibre length across the entire ring topology network; and

Figure 16 is a view showing yet another general embodiment of the invention, utilising a counter-propagating sensing and locating arrangement and a plurality of WDM couplers in an optical fibre ring topology network arrangement, forming several junction by-pass arrangements for the sensing signals in order to extend the overall sensing fibre length across the entire ring topology network.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the invention, without imposing any limitations, will be further described with reference to the above mentioned drawings. The drawings and the following embodiments are provided in as general a form as possible to avoid confusion. While it may not be specifically stated or illustrated in the following embodiments and drawings, in the preferred embodiments the following features are utilised, and not intentionally omitted, where appropriate:

- the distributed sensing technique is based on a modalmetric technique utilising the fusion splicing of insensitive singlemode fibre to sensitive multimode fibre;
- the transmissive counter-propagating signal method for locating events is employed, where appropriate, and suitable optical devices are employed at one or both ends of the system to detect and process the signals;
- further silica waveguides are connected to the main silica waveguide communication link at either or both ends in order to provide insensitive lead waveguides and, if applicable, to add additional delay between the transmissive counter-propagating signals;

- any suitable light source, coupler and photodetector arrangement may be used with the sensor and locating systems. In a preferred embodiment, the required optical properties of the light source are such that light may be launched into and propagated in the singlemode waveguide. For localisation, the light propagated in a singlemode fibre must remain singlemoded during the entire period of travel in the singlemode fibre. Once the light is launched into the multimode fibre from the singlemode fibre, several modes may be excited and the multimoded fibre will be sensitive to various parameters. Once the light is launched back into the singlemode fibre from the multimode fibre, only a single mode is supported and travels to the optical components of the system. Lead-in/lead-out fibre desensitisation and sensor localisation is achieved in this manner. In practical applications, the singlemode fibre should be made sufficiently long to attenuate all cladding modes in order to improve the signal-to-noise ratio. This preferred embodiment applies for both directions of travel of the transmissive counter-propagating optical signals where this technique is utilised;
- utilisation of properties and characteristics of the electromagnetic radiation propagating in the waveguide sensor enables monitoring to take place in a non-destructive manner. Thus, the sensor is not necessarily damaged, fractured or destroyed in order to monitor and locate the desired parameter;
- utilisation of all-fibre, low-cost optical devices in conjunction with laser diodes, light emitting diodes, photodetectors, couplers, WDM couplers, isolators and filters;
- the wavelength multiplexing/demultiplexing (WDM) couplers are 2x1 WDM couplers, in other embodiments they may be any suitable multi-port device, such as 2x2, 3x1, 4x2, etc.; and

- the optical fibres and fibre devices are connected by fusion splices. In another embodiments the optical fibres and fibre devices are connected by any suitable or appropriate technique, such as mechanical splices, connectorised leads and through-adaptors, etc.

Figure 1 illustrates the configuration used for the demonstration of a simultaneous fibre optic communications and sensing system. The system configuration consisted of the fibre link 1, either single or multi moded, with standard 3 dB (50% splitting ratio), 2x2 fibre couplers 3a and 3b at each end to allow for the multiplexing and demultiplexing of the two wavelengths at the transmitter 2a and 4a and receiver ends 2b and 4b, respectively. The choice of sensing wavelength was important as the responsivity of the InGaAs detector 2b in the communications channel needed to be negligible at the sensing wavelength. Thus, the communications channel was chosen to operate at a wavelength of 1300 nm whilst the sensing channel was chosen to operate at either 633 nm or 850 nm. This ensured that inter-channel crosstalk was negligible, as the Si detector 4b utilised in the sensing channel would not respond to the 1300 nm communications signal.

The content of our aforesaid International Application Nos. PCT/AU95/00568 and PCT/AU99/01028 is incorporated into this specification by this reference.

Figures 2a, to 2d show the results from the sensing arrangement shown in Figure 1 when a vibrational disturbance was applied to a short section of the fibre link using a cantilever beam arrangement. The fibre was simply taped longitudinally along the beam length. Results are shown for a 28 km singlemode (SM) link and a 53 km multimode (MM) fibre link. As can be seen, very good signal quality was obtained. In addition, the Fast

Fourier Transforms (FFTs) clearly identify the natural frequency of the beam to be ~18 Hz with both links.

Figure 3 shows the basic principle of the waveguide transmissive counter-propagating signal method for locating events in fibre optic sensing systems. The technique relies on the measurement of the time delay or difference between transmissive counter-propagating optical signals affected by the same event in a two-ended fibre arrangement. In this novel arrangement, continuous-wave (CW) optical signals are simultaneously launched, preferably from a single light source, into opposite ends of a sensing optical fibre or set of fibres and simultaneously detected by synchronised photodetectors. Any sensed parameter which acts to alter the counter-propagating signals will effect both signals in the same manner. However, because the effected counter-propagating signals must each continue travelling the remainder of the fibre length to their respective photodetectors there is a resultant time delay or time difference between the detected signals. The time delay is directly proportional to the location of the sensed event along the fibre length referenced from Port 1 according to the following formula:

$$Point\ of\ disturbance_{Port1} = \frac{d_x - (v\Delta t)}{2} \qquad (1)$$

where d_x is the total length of the optical fibre link, Δt is the resultant time delay or time difference between the detected signals and v is the speed of the optical signal given by c/n_{fibre}, where c is the speed of light in a vacuum (3×10^8 m/s) and n_{fibre} is the effective refractive index of the optical fibre.

Similarly, the point of disturbance referenced from Port 2 is given by:

$$Point\ of\ disturbance_{Port2} = \frac{d_x + (v\Delta t)}{2} \qquad (2)$$

Therefore, if the time delay or difference is detected and measured, the location of the event can be determined. At the same time, if a compatible sensing mechanism is being employed the sensed event can be quantified and/or identified (ie., strain, vibration, acoustic emission, temperature transients, etc.). In addition, non-sensitive fibre optic delay lines may be connected to the sensing fibre at either or both ends in order to add additional delay between the transmissive counter-propagating signals and to provide insensitive lead fibres. This may assist engineering the technique into a practical working system.

It is interesting to note that this result illustrates that it is required to only know the length of the entire fibre link, d_x , and not the respective lengths of the various sensitive and insensitive fibre regions in the system. This information can be easily obtained at the design and installation stages of a project, or post-installation by the use of an OTDR. Then, once the total length is known and the time delay, Δt, is measured by the system, it is a straight forward calculation using Equations 1 or 2 to determine the location of the sensed event.

Figure 4 shows a combined fibre optic sensing and communications arrangement, utilising a modalmetric sensing technique and the ability to locate disturbances formed by the method of Figure 3. In a practical application of this technique, it will usually be desirable for both launch points of the counter-propagating signals to be at the same physical location. One method in which this can easily be achieved is by using a multi-fibre cable which will effectively form a single-ended system. In this arrangement, one singlemode fibre 1 is utilised as the communications fibre, whilst two fibres 2 and 3, one singlemode and one multimode, are required to set-up the modalmetric intrusion sensor (event

detection and location determination) over the specified region of interest (within sleeve 4). A perturbation P anywhere along the multimode fibre sleeve 4 will generate two counter-propagating perturbation signals. Measuring the time difference in their respective time of arrival at the transmitter end of the link will allow the location of the disturbance to be determined.

Figure 5 is a view showing a general embodiment of the present invention for a transmissive sensing arrangement operating over a singlemode optical fibre telecommunication link. With reference to Figure 5, according to a preferred embodiment of the present invention, coherent laser light at the sensing wavelength 980 nm is launched into a 980 nm singlemode optical fibre 6a from a pigtailed laser diode with optional integrated isolator 40 and propagates along the optical fibre 6a. The optical fibre 6a is fusion spliced 57 to one input arm 6b of a 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 30 and when the light at the sensing wavelength reaches the coupler 30 it is branched out into the output arm 5a of the coupler 30. Simultaneously, laser light at the communications wavelength 1550 nm is launched into a 1550 nm singlemode optical fibre 7a from a pigtailed laser diode with optional integrated isolator 20 and propagates along the optical fibre 7a. The optical fibre 7a is fusion spliced 50 to the second input arm 7b of the 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 30 and when the light at the communications wavelength reaches the coupler 30 it is likewise branched out into the same output arm 5a of the coupler 30 as the sensing signal. Thus, the wavelength multiplexing coupler 30 efficiently combines both the sensing and communications signals into a single output coupler arm 5a. The output arm 5a of the wavelength multiplexing coupler 30 is then fusion spliced 52 directly to the main 1550 nm singlemode optical fibre transmission

link 1000. Both the communications and sensing signals propagate along the entire length of the 1550 nm singlemode optical fibre transmission link 1000, without interfering with one another, until they reach the opposite end of the link 1000. The 1550 nm singlemode optical fibre transmission link 1000 is then fusion spliced 54 to the input arm 5b of a 980/1550 nm singlemode fibre optic wavelength demultiplexing coupler 32 and when the signals reach the coupler 32 they are efficiently separated and branched out into two separate and respective output arms 6c and 7c of the coupler 32. The 980 nm sensing signal output arm 6c of the wavelength demultiplexing coupler 32 is then fusion spliced 58 to a 980 nm singlemode fibre 6d pigtailed InGaAs detector 42. Similarly, the 1550 nm communications signal output arm 7c of the wavelength demultiplexing coupler 32 is then fusion spliced 56 to a 1550 nm singlemode fibre 7d which is connected to pigtailed InGaAs detector 22. Finally, appropriate electronics, signal processing schemes and algorithms process the signals from the photodetectors to obtain the desired information.

Figure 6 is a view showing a general embodiment of the invention for a reflective sensing arrangement operating over a singlemode optical fibre telecommunication link. In the embodiment of Figure 6, according to a preferred arrangement of the present invention, coherent laser light at the sensing wavelength 980 nm is launched into a 980 nm singlemode optical fibre 6a from a pigtailed laser diode with optional integrated isolator 40 and propagates along the optical fibre 6a. The optical fibre 6a is fusion spliced 60 to one input arm 6e of a 980 nm singlemode coupler 44 and when the light at the sensing wavelength reaches the coupler 44 it is branched out into the output arm 6g of the coupler 44. If a wavelength multiplexing coupler with two output arms is used then the unused arm is fractured or otherwise terminated to avoid back-

reflections. The light at the sensing wavelength then propagates along optical fibre 6g. The optical fibre 6g is fusion spliced 62 to one input arm 6b of a 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 30 and when the light at the sensing wavelength reaches the coupler 30 it is branched out into the output arm 5a of the coupler 30. Simultaneously, laser light at the communications wavelength 1550 nm is launched into a 1550 nm singlemode optical fibre 7a from a pigtailed laser diode with optional integrated isolator 20 and propagates along the optical fibre 7a. The optical fibre 7a is fusion spliced 50 to the second input arm 7b of the 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 30 and when the light at the communications wavelength reaches the coupler 30 it is likewise branched out into the same output arm 5a of the coupler 30 as the sensing signal. Thus, the wavelength multiplexing coupler 30 efficiently combines both the sensing and communications signals into a single output coupler arm 5a. The output arm 5a of the wavelength multiplexing coupler 30 is then fusion spliced 52 directly to the main 1550 nm singlemode optical fibre transmission link 1000. Both the communications and sensing signals propagate along the entire length of the 1550 nm singlemode optical fibre transmission link 1000, without interfering with one another, until they reach the opposite end of the link 1000. The 1550 nm singlemode optical fibre transmission link 1000 is then fusion spliced 54 to the input arm 5b of a 980/1550 nm singlemode fibre optic wavelength demultiplexing coupler 32 and when the signals reach the coupler 32 they are efficiently separated and branched out into two separate and respective output arms 6c and 7c of the coupler 32. The 1550 nm communications signal output arm 7c of the wavelength demultiplexing coupler 32 is then fusion spliced 56 to a 1550 nm singlemode fibre 7d pigtailed InGaAs detector 22. The 980 nm sensing signal output arm 6c of the wavelength demultiplexing coupler 32

is then fusion spliced 64 to a 980 nm singlemode fibre 6h terminated with a reflective mirror 46. The sensing signal is thus reflected back in the opposite direction along fibres 6h, 6c, 5b, 1000, 5a, 6b and 6g, and branched through coupler 44 to output arm 6f. Thus the sensing signal propagates along the entire length of the 1550 nm singlemode optical fibre transmission link 1000 twice, effectively doubling sensitivity. The output arm 6f of the coupler 44 is then fusion spliced 66 to a 980 nm singlemode fibre 6d pigtailed InGaAs detector 42. Finally, appropriate electronics, signal processing schemes and algorithms process the signals from the photodetectors to obtain the desired information.

Figure 7 is a view showing another general embodiment of the invention for a two-ended counter-propagating sensing and locating arrangement, according to the method shown in Figure 3, operating over a singlemode optical fibre telecommunication link. A 980 nm counter-propagating sensing system 300 is used to launch a sensing signal in one direction of the 1550 nm singlemode optical fibre transmission link 1000 and the system 300 is suitably time-synchronised with a second 980 nm counter-propagating sensing system 320 launching a sensing signal in the opposite direction of the 1550 nm singlemode optical fibre transmission link 1000. Any disturbance P that acts to alter the counter-propagating sensing signals along link 1000 will effect both signals in the same manner. However, because the effected counter-propagating signals must each continue travelling the remainder of the fibre length to their respective photodetectors in systems 300 and 320 there is a resultant time delay or time difference between the detected signals. The time delay is directly proportional to the location of the sensed event along the fibre length, as described earlier. Time synchronisation between system 300 and 320 is important in determining the time difference between the counter-propagating signals.

Figure 8 is a view showing yet another general embodiment of the invention for a single-ended counter-propagating sensing and locating arrangement, according to the method shown in Figure 4, operating over a singlemode optical fibre telecommunication link. A single-ended 980 nm counter-propagating sensing system 350 is used to simultaneously launch, propagate and monitor two counter-propagating sensing signals in the 1550 nm singlemode optical fibre transmission link 1000 fusion spliced 74 to another optical fibre (single or multi moded) in the same or nearby cable 1200. Any disturbance P that acts to alter the counter-propagating sensing signals along links 1000 and/or 1200 will effect both signals in the same manner. However, because the effected counter-propagating signals must each continue travelling the remainder of the fibre length to their respective photodetectors in system 350 there is a resultant time delay or time difference between the detected signals. The time delay is directly proportional to the location of the sensed event along the fibre length, as described earlier. Time synchronisation in this case can be easily achieved by utilising a common signal acquisition system.

Figure 9 is a view showing another general embodiment of the present invention for a transmissive sensing arrangement operating over a multimode optical fibre telecommunication link. With reference to Figure 9, according to another preferred embodiment of the present invention, coherent laser light at the sensing wavelength 1310 nm is launched into a 1310 nm singlemode optical fibre 8a from a pigtailed laser diode with optional integrated isolator 41 and propagates along the optical fibre 8a. The optical fibre 8a is fusion spliced 84 to one input arm 8b of a 850/1310 nm multimode fibre optic wavelength multiplexing coupler 34 and when the light at the sensing wavelength reaches the coupler 34 it is

branched out into the output arm 5c of the coupler 34. Simultaneously, laser light at the communications wavelength 850 nm is launched into a multimode optical fibre 9a from a pigtailed laser diode with optional integrated isolator 25 and propagates along the optical fibre 9a. The optical fibre 9a is fusion spliced 80 to the second input arm 9b of the 850/1310 nm multimode fibre optic wavelength multiplexing coupler 34 and when the light at the communications wavelength reaches the coupler 34 it is likewise branched out into the same output arm 5c of the coupler 34 as the sensing signal. Thus, the wavelength multiplexing coupler 34 efficiently combines both the sensing and communications signals into a single output coupler arm 5c. The output arm 5c of the wavelength multiplexing coupler 34 is then fusion spliced 81 directly to the main multimode optical fibre transmission link 1500. Both the communications and sensing signals propagate along the entire length of the multimode optical fibre transmission link 1500, without interfering with one another, until they reach the opposite end of the link 1500. The multimode optical fibre transmission link 1500 is then fusion spliced 82 to the input arm 5d of a 850/1310 nm multimode fibre optic wavelength demultiplexing coupler 36 and when the signals reach the coupler 36 they are efficiently separated and branched out into two separate and respective output arms 8c and 9c of the coupler 36. The 1310 nm sensing signal output arm 8c of the wavelength demultiplexing coupler 36 is then fusion spliced 88 to a 1310 nm singlemode fibre 8d pigtailed InGaAs detector 43. Similarly, the 850 nm communications signal output arm 9c of the wavelength demultiplexing coupler 36 is then fusion spliced 83 to a multimode fibre 9d pigtailed or receptacled Si detector 27. Finally, appropriate electronics, signal processing schemes and algorithms process the signals from the photodetectors to obtain the desired information.

Figure 10 is a view showing another general embodiment of the invention for a reflective sensing arrangement operating over a multimode optical fibre telecommunication link. In the embodiment of Figure 10, according to another preferred arrangement of the present invention, coherent laser light at the sensing wavelength 1310 nm is launched into a 1310 nm singlemode optical fibre 8a from a pigtailed laser diode with optional integrated isolator 41 and propagates along the optical fibre 8a. The optical fibre 8a is fusion spliced 86 to one input arm 8e of a 1310 nm singlemode coupler 45 and when the light at the sensing wavelength reaches the coupler 45 it is branched out into the output arm 8g of the coupler 45. If a coupler with two output arms is used then the unused arm is fractured or otherwise terminated to avoid back-reflections. The light at the sensing wavelength then propagates along optical fibre 8g. The optical fibre 8g is fusion spliced 87 to one input arm 8b of a 850/1310 nm multimode fibre optic wavelength multiplexing coupler 34 and when the light at the sensing wavelength reaches the coupler 34 it is branched out into the output arm 5c of the coupler 34. If a wavelength multiplexing coupler with two output arms is used then the unused arm is fractured or otherwise terminated to avoid back-reflections. Simultaneously, laser light at the communications wavelength 850 nm is launched into a multimode optical fibre 9a from a pigtailed laser diode with optional integrated isolator 25 and propagates along the optical fibre 9a. The optical fibre 9a is fusion spliced 80 to the second input arm 9b of the 850/1310 nm multimode fibre optic wavelength multiplexing coupler 34 and when the light at the communications wavelength reaches the coupler 34 it is likewise branched out into the same output arm 5c of the coupler 34 as the sensing signal. Thus, the wavelength multiplexing coupler 34 efficiently combines both the sensing and communications signals into a single output coupler arm 5c. The output arm 5c of the

wavelength multiplexing coupler 34 is then fusion spliced 81 directly to the main multimode optical fibre transmission link 1500. Both the communications and sensing signals propagate along the entire length of the multimode optical fibre transmission link 1500, without interfering with one another, until they reach the opposite end of the link 1500. The multimode optical fibre transmission link 1500 is then fusion spliced 82 to the input arm 5d of a 850/1310 nm multimode fibre optic wavelength demultiplexing coupler 36 and when the signals reach the coupler 36 they are efficiently separated and branched out into two separate and respective output arms 8c and 9c of the coupler 36. The 850 nm communications signal output arm 9c of the wavelength demultiplexing coupler 36 is then fusion spliced 83 to a multimode fibre 9d pigtailed or receptacled Si detector 27. The 1310 nm sensing signal output arm 8c of the wavelength demultiplexing coupler 36 is then fusion spliced 88 to a 1310 nm singlemode or multimode fibre 8h terminated with a reflective mirror 47. The sensing signal is thus reflected back in the opposite direction along fibres 8h, 8c, 5d, 1500, 5c, 8b and 8g, and branched through coupler 45 to output arm 8f. Thus the sensing signal propagates along the entire length of the multimode optical fibre transmission link 1500 twice, effectively doubling sensitivity. The output arm 8f of the coupler 45 is then fusion spliced 89 to a 1310 nm singlemode fibre 8d pigtailed InGaAs detector 43. Finally, appropriate electronics, signal processing schemes and algorithms process the signals from the photodetectors to obtain the desired information.

Figure 11 is a view showing another general embodiment of the invention for a two-ended counter-propagating sensing and locating arrangement, according to the method shown in Figure 3, operating over a multimode optical fibre telecommunication link. A 1310 nm counter-propagating

sensing system 400 is used to launch a sensing signal in one direction of the main multimode optical fibre transmission link 1500 and the system 400 is suitably time-synchronised with a second 1310 nm counter-propagating sensing system 420 launching a sensing signal in the opposite direction of the main multimode optical fibre transmission link 1500. Any disturbance that acts to alter the counter-propagating sensing signals along link 1500 will effect both signals in the same manner. However, because the effected counter-propagating signals must each continue travelling the remainder of the fibre length to their respective photodetectors in systems 400 and 420 there is a resultant time delay or time difference between the detected signals. The time delay is directly proportional to the location of the sensed event along the fibre length, as described earlier. Time synchronisation between system 400 and 420 is important in determining the time difference between the counter-propagating signals.

Figure 12 is a view showing another general embodiment of the invention for a single-ended counter-propagating sensing and locating arrangement, according to the method shown in Figure 4, operating over a multimode optical fibre telecommunication link. A single-ended 1310 nm counter-propagating sensing system 450 is used to simultaneously launch, propagate and monitor two counter-propagating sensing signals in the main multimode optical fibre transmission link 1500 fusion spliced 94 to another optical fibre (single or multi moded) in the same or nearby cable 1700. Any disturbance that acts to alter the counter-propagating sensing signals along links 1500 and/or 1700 will effect both signals in the same manner. However, because the effected counter-propagating signals must each continue travelling the remainder of the fibre length to their respective photodetectors in system 450 there is a resultant time delay or time difference between the detected signals. The time delay is directly

proportional to the location of the sensed event along the fibre length, as described earlier. Time synchronisation in this case can be easily achieved by utilising a common signal acquisition system.

Figure 13 is a view showing a further general embodiment of the invention, utilising a plurality of WDM couplers in a singlemode optical fibre, three-node, point-to-point network arrangement, forming a junction by-pass arrangement for the sensing signal in order to extend the sensing fibre length beyond one communication node. With reference to Figure 13, according to a further preferred embodiment of the present invention, starting at Communications Node 1 N1 coherent laser light at the sensing wavelength 980 nm is launched into a 980 nm singlemode optical fibre 16a from a pigtailed laser diode with optional integrated isolator 140 and propagates along the optical fibre 16a. The optical fibre 16a is fusion spliced 157 to one input arm 16b of a 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 130 and when the light at the sensing wavelength reaches the coupler 130 it is branched out into the output arm 15a of the coupler 130. Simultaneously, at Communications Node 1 laser light at the communications wavelength 1550 nm is launched into a 1550 nm singlemode optical fibre 17a from a pigtailed laser diode with optional integrated isolator 120 and propagates along the optical fibre 17a. The optical fibre 17a is fusion spliced 150 to the second input arm 17b of the 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 130 and when the light at the communications wavelength reaches the coupler 130 it is likewise branched out into the same output arm 15a of the coupler 130 as the sensing signal. Thus, the wavelength multiplexing coupler 130 efficiently combines both the sensing and communications signals into a single output coupler arm 15a. The output arm 15a of the wavelength multiplexing coupler 130 is then fusion spliced

152 directly to the main 1550 nm singlemode optical fibre transmission link 2000. Both the communications and sensing signals propagate along the entire length of the 1550 nm singlemode optical fibre transmission link 2000, without interfering with one another, until they reach the opposite end of the link 2000. The 1550 nm singlemode optical fibre transmission link 2000 is then fusion spliced 154 to the input arm 15b of a 980/1550 nm singlemode fibre optic wavelength demultiplexing coupler 132 and when the signals reach the coupler 132 they are efficiently separated and branched out into two separate and respective output arms 16c and 17c of the coupler 132. The 1550 nm communications signal output arm 17c of the wavelength demultiplexing coupler 132 is then fusion spliced 156 to a 1550 nm singlemode fibre 17d pigtailed InGaAs detector 122 at Communications Node 2 N2, where appropriate electronics, signal processing schemes and algorithms process the signals from the photodetector 122 to obtain the desired communications information. The 980 nm sensing signal output arm 16c of the wavelength demultiplexing coupler 132 is then fusion spliced 158 to a 980 nm or 1550 nm singlemode optical fibre 2001 which acts to by-pass Communications Node 2 so that the sensing signal continuous propagating towards Communications Node 3 N3. Continuing on, the sensing signal thus propagates along junction by-pass fibre 2001 until fibre 2001 is fusion spliced 257 to one input arm 116b of a 980/1550 nm singlemode fibre optic wavelength multiplexing coupler 230 and when the light at the sensing wavelength reaches the coupler 230 it is branched out into the output arm 115a of the coupler 230. Simultaneously, at Communications Node 2 laser light at the communications wavelength 1550 nm is launched into a 1550 nm singlemode optical fibre 117a from a pigtailed laser diode with optional integrated isolator 220 and propagates along the optical fibre 117a. The optical fibre 117a is fusion spliced 250 to the second input arm 117b of the 980/1550 nm singlemode fibre optic

wavelength multiplexing coupler 230 and when the light at the communications wavelength reaches the coupler 230 it is likewise branched out into the same output arm 115a of the coupler 230 as the sensing signal. Thus, the wavelength multiplexing coupler 230 efficiently combines both the sensing and communications signals into a single output coupler arm 115a. The output arm 115a of the wavelength multiplexing coupler 230 is then fusion spliced 252 directly to the second main 1550 nm singlemode optical fibre transmission link 2002. Both the communications and sensing signals propagate along the entire length of the 1550 nm singlemode optical fibre transmission link 2002, without interfering with one another, until they reach the opposite end of the link 2002. The 1550 nm singlemode optical fibre transmission link 2002 is then fusion spliced 254 to the input arm 115b of a 980/1550 nm singlemode fibre optic wavelength demultiplexing coupler 232 and when the signals reach the coupler 232 they are efficiently separated and branched out into two separate and respective output arms 116c and 117c of the coupler 232. The 1550 nm communications signal output arm 117c of the wavelength demultiplexing coupler 232 is then fusion spliced 256 to a 1550 nm singlemode fibre 117d pigtailed InGaAs detector 222 at Communications Node 3. Similarly, the 980 nm sensing signal output arm 116c of the wavelength demultiplexing coupler 232 is then fusion spliced 258 to a 980 nm singlemode fibre 116d pigtailed InGaAs detector 242. Finally, appropriate electronics, signal processing schemes and algorithms at Communications Node 3 process the signals from the photodetectors to obtain the desired information. In this method, the sensing signal was propagated along two optical fibre links 2000 and 2002, while still utilising only one transmitter 140 end and one detector 242 end.

At the 980 nm sensing wavelength it is possible to also use true multimode fibre in place of the singlemode fibres

2000, 2001 and 2002 if the communications system was operating over a multimode link.

Figure 14 is a view showing a further general embodiment of the invention, utilising a plurality of WDM couplers in a multimode optical fibre, three-node, point-to-point network, forming a junction by-pass arrangement for the sensing signal in order to extend the sensing fibre length beyond one communication node. With reference to Figure 14, according to a further preferred embodiment of the present invention, starting at Communications Node 1 coherent laser light at the sensing wavelength 1310 nm is launched into a multimode optical fibre 18a from a pigtailed laser diode with optional integrated isolator 141 and propagates along the optical fibre 18a. The optical fibre 18a is fusion spliced 184 to one input arm 18b of a 850/1310 nm multimode fibre optic wavelength multiplexing coupler 134 and when the light at the sensing wavelength reaches the coupler 134 it is branched out into the output arm 15c of the coupler 134. Simultaneously, at Communications Node 1 laser light at the communications wavelength 850 nm is launched into a multimode optical fibre 19a from a pigtailed laser diode with optional integrated isolator 125 and propagates along the optical fibre 19a. The optical fibre 19a is fusion spliced 180 to the second input arm 19b of the 850/1310 nm multimode fibre optic wavelength multiplexing coupler 134 and when the light at the communications wavelength reaches the coupler 134 it is likewise branched out into the same output arm 15c of the coupler 134 as the sensing signal. Thus, the wavelength multiplexing coupler 134 efficiently combines both the sensing and communications signals into a single output coupler arm 15c. The output arm 15c of the wavelength multiplexing coupler 134 is then fusion spliced 181 directly to the main multimode optical fibre transmission link 2150. Both the communications and sensing signals propagate along the entire length of the

multimode optical fibre transmission link 2150, without interfering with one another, until they reach the opposite end of the link 2150. The multimode optical fibre transmission link 2150 is then fusion spliced 182 to the input arm 15d of a 850/1310 nm multimode fibre optic wavelength demultiplexing coupler 136 and when the signals reach the coupler 136 they are efficiently separated and branched out into two separate and respective output arms 18c and 19c of the coupler 136. The 850 nm communications signal output arm 19c of the wavelength demultiplexing coupler 136 is then fusion spliced 183 to a multimode fibre 19d pigtailed or receptacled Si detector 127 at Communications Node 2, where appropriate electronics, signal processing schemes and algorithms process the signals from the photodetector 127 to obtain the desired communications information. The 1310 nm sensing signal output arm 18c of the wavelength demultiplexing coupler 136 is then fusion spliced 188 to a multimode or 1310 nm singlemode optical fibre 2160 which acts to by-pass Communications Node 2 so that the sensing signal continuous propagating towards Communications Node 3. Continuing on, the sensing signal thus propagates along junction by-pass fibre 2160 until fibre 2160 is fusion spliced 284 to one input arm 118b of a 850/1310 nm multimode fibre optic wavelength multiplexing coupler 234 and when the light at the sensing wavelength reaches the coupler 234 it is branched out into the output arm 115c of the coupler 234. Simultaneously, at Communications Node 2 laser light at the communications wavelength 850 nm is launched into a multimode optical fibre 119a from a pigtailed laser diode with optional integrated isolator 225 and propagates along the optical fibre 119a. The optical fibre 119a is fusion spliced 280 to the second input arm 119b of the 850/1310 nm multimode fibre optic wavelength multiplexing coupler 234 and when the light at the communications wavelength reaches the coupler 234 it is likewise branched out into the same output arm 115c of

the coupler 234 as the sensing signal. Thus, the wavelength multiplexing coupler 234 efficiently combines both the sensing and communications signals into a single output coupler arm 115c. The output arm 115c of the wavelength multiplexing coupler 234 is then fusion spliced 281 directly to the second main multimode optical fibre transmission link 2170. Both the communications and sensing signals propagate along the entire length of the multimode optical fibre transmission link 2170, without interfering with one another, until they reach the opposite end of the link 2170. The multimode optical fibre transmission link 2170 is then fusion spliced 282 to the input arm 115d of a 850/1310 nm multimode fibre optic wavelength demultiplexing coupler 236 and when the signals reach the coupler 236 they are efficiently separated and branched out into two separate and respective output arms 118c and 119c of the coupler 236. The 850 nm communications signal output arm 119c of the wavelength demultiplexing coupler 236 is then fusion spliced 283 to a multimode fibre 119d pigtailed or receptacled Si detector 227 at Communications Node 3. Similarly, the 1310 nm sensing signal output arm 118c of the wavelength demultiplexing coupler 236 is then fusion spliced 288 to a multimode or 1310 nm singlemode fibre 118d pigtailed InGaAs detector 243. Finally, appropriate electronics, signal processing schemes and algorithms at Communications Node 3 process the signals from the photodetectors to obtain the desired information. In this method, the sensing signal was propagated along two optical fibre links 2150 and 2170, while still utilising only one transmitter 141 end and one detector 243 end.

Figure 15 is a view showing yet another general embodiment of the invention, utilising a transmissive sensing arrangement and a plurality of WDM couplers in an optical fibre ring topology network, forming several junction by-pass arrangements for the sensing signal in order to extend the overall sensing fibre length across the entire

ring topology network. In this arrangement, ring topology network (RTN) nodes 500, 502, 504, 506, 508 and 510 are interconnected via optical fibre (single or multi moded) links 600, 602, 604, 606, 608 and 610 by a logical sequence of appropriate WDM couplers 550, 552, 554, 556, 558, 560, 562, 564, 566, 568, 570 and 572. Meanwhile, a sensing signal is launched from a pigtailed laser diode with optional isolator 520 around the network fibres 600, 602, 604, 606, 608 and 610 by the same logical sequence of appropriate WDM couplers 550, 552, 554, 556, 558, 560, 562, 564, 566, 568, 570 and 572 and junction by-pass fibres (single or multi moded) 650, 652, 654, 656 and 658 until the signal is finally received at detector 540, in a similar fashion as that described in detail for Figures 13 and 14. The advantage of this arrangement is that the overall sensing fibre length was extended across the entire ring topology network, while still utilising only one transmitter 520 end and one detector 540 end.

Figure 16 is a view showing yet another general embodiment of the invention, utilising a counter-propagating sensing and locating arrangement and a plurality of WDM couplers in an optical fibre ring topology network arrangement, forming several junction by-pass arrangements for the sensing signals in order to extend the overall sensing fibre length across the entire ring topology network. In this arrangement, ring topology network (RTN) nodes 700, 702, 704, 706, 708 and 710 are interconnected via optical fibre (single or multi moded) links 800, 802, 804, 806, 808 and 810 by a logical sequence of appropriate WDM couplers 750, 752, 754, 756, 758, 760, 762, 764, 766, 768, 770 and 772. Meanwhile, a counter-propagating sensing system 720 simultaneously launches counter-propagating sensing signals around the network fibres 800, 802, 804, 806, 808 and 810 by the same logical sequence of appropriate WDM couplers 750, 752, 754, 756, 758, 760, 762, 764, 766, 768, 770 and 772 and junction by-pass fibres (single or multi moded) 850, 852, 854, 856 and 858

until the signals are finally received at synchronised detectors in the counter-propagating sensing system 720, in a similar fashion as that described in detail in the other figures. The advantage of this arrangement is that the overall sensing fibre length was extended across the entire ring topology network, while utilising only a single instrument control box, with individual optical fibre input/output ports.

APPLICATIONS OF THE PREFERRED EMBODIMENTS

Communications using optical fibres have a number of attractive features and advantages over conventional communication means, and their performance has been proven over the past two decades. The value offered by these systems has now been augmented by the ability to simultaneously monitor, in real-time, the integrity of the cable, as well as any structure or material near the cable or to which the cable is attached. This attractive and useful new feature should increase the demand for the technology.

Not inclusive, but indicatively, the following examples illustrates the applications in which a combined communications and sensing (dual) system may be used:

Any fibre optic communications systems which need to be monitored against and detect intrusion, tampering or tapping-off of information from the optical fibres, such as:

Singlemode or multimode information technology (IT) networks and links

Singlemode local area networks (LANs)

Multimode local area networks (LANs)

Singlemode wide area networks (WANs)

Multimode wide area networks (WANs)

Short-haul telecommunications

Long-haul telecommunications

Private fibre optic links and networks

Public fibre optic links and networks

Commercial fibre optic links and networks
Government fibre optic links and networks
Military fibre optic links and networks
Defence fibre optic links and networks
Embassy fibre optic links and networks
Industrial fibre optic links and networks
Financial organisation fibre optic links and networks
Any fibre optic communications systems which are also utilised for sensing applications, including:

- Public telecommunications
- Private telecommunications
- Information technology networks
- National security
- Industrial security
- Law enforcement
- Counter-intelligence
- Physical perimeter security
- Intrusion detection & location
- Pipeline integrity monitoring
- Pipeline third party interference detection & location
- Pipeline leak detection & location
- Public road authorities
- Private road ventures
- Railway authorities and freight operators
- Road transport operators

Any fibre optic sensing systems which are also utilised for telecommunications, including:

- Public telecommunications
- Private telecommunications
- Information technology networks
- National security
- Industrial security
- Law enforcement
- Counter-intelligence
- Physical perimeter security
- Intrusion detection & location

- Pipeline integrity monitoring
- Pipeline third party interference detection & location
- Pipeline leak detection & location
- Land and offshore building & construction structural integrity monitoring & design
- Machine performance monitoring & design
- Rail stock monitoring (Flat spot detection)
- Power generation and transmission companies
- Petro-chemical & industrial plant monitoring & design organisations
- Aerospace/aviation design and maintenance organisations
- Public road authorities
- Private road ventures
- Railway authorities and freight operators
- Road transport operators
- Airline operators
- Mining companies
- Earthquake monitoring organisations
- Oceanographic companies

Since modifications within the spirit and scope of the invention may readily be effected by persons skilled within the art, it is to be understood that this invention is not limited to the particular embodiments described by way of example hereinabove.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An optical waveguide communication link, including;

a waveguide for conveying signals from one location to another location;

a data transmitter for launching a data signal at a first wavelength into the waveguide;

a data receiver for receiving the data signal from the waveguide;

a sensing signal transmitter for launching a sensing signal at a second wavelength different to the first wavelength, into the waveguide;

a sensing signal detector for detecting the sensing signal after the sensing signal has travelled through the waveguide; and

signal splitting means between the waveguide and the data receiver and the sensing signal detector so that the signal at the first wavelength is separated from the sensing signal at the second wavelength by the signal splitting means so that substantially all of the data signal without significant loss and without any significant component of the sensing signal is directed to the data receiver, and substantially all of the sensing signal without any significant loss and without any significant component of the data signal is directed to the sensing signal detector.

2. The link of claim 1 wherein the signal splitting means comprises a wavelength multiplexing/demultiplexing waveguide coupler.

3. The link of claim 1 wherein the data signal from the waveguide and the sensing signal from the sensing signal transmitter are received by a wavelength multiplexing/demultiplexing coupler to combine the signals for transmission along the waveguide.

4. The link of claim 1 wherein the sensing signal transmitter and sensing signal detector are at the said one location and said another location respectively.

5. The link of claim 1 wherein the sensing signal transmitter and the sensing signal detector are located both at one or the other of the said one location or the another location and wherein a reflector is provided for reflecting the sensing signal back through the waveguide after separation of the sensing signal from the data signal by the signal splitting means.

6. The link of claim 5 wherein the reflector comprises a reflective mirror.

7. The link of any one of claims 1 to 5 wherein the sensing signal transmitter comprises a counter-propagating sensing signal transmitter for launching counter-propagating sensing signals into the waveguide and travel in opposite directions through the waveguide to enable the position of any disturbance to the waveguide to be determined by the difference between the time a perturbing sensing event is detected in both counter-current sensing signals.

8. The link of claim 1 wherein processing means is provided for processing the sensing signal to determine a change in parameter within the signal to identify a disturbance to the waveguide indicative of tampering with the waveguide.

9. The link of claim 1 wherein the communication link includes a plurality of communication nodes, at least one of the nodes including a said data transmitter, a second node including a said data receiver and a further said data transmitter, and a third node including at least a further said data receiver, the waveguide

interconnecting each of the nodes so that the sensing signal passes through the waveguide from the first node to the third node.

10. The link of claim 1 wherein the waveguide forms a continuous loop including a plurality of communication nodes arranged along the loop, at least one of the loop häving a said sensing signal transmitter and a said sensing signal detector.

11. A said signal combining means is provided for directing a data signal from a data transmitter at one of the nodes, to a said data receiver at another of the nodes.

12. An optical waveguide communication link including;

a waveguide for conveying signals from one location to another location;

a data transmitter for launching a data signal into the waveguide;

a first wavelength multiplexing/demultiplexing waveguide device coupled to the waveguide, the waveguide device having a first output arm and a second output arm;

a sensing signal transmitter for launching sensing signal having a wavelength different to the wavelength of the data signal into the waveguide for transmission with the data signal along the waveguide;

a data receiver coupled to the first output arm for receiving the data signal from the waveguide device;

a sensing signal detector coupled to the second output arm for receiving a sensing signal from the waveguide device.

13. The link of claim 12 the waveguide device comprises a wavelength multiplexing/demultiplexing coupler.

14. The link of claim 12 wherein a second waveguide device is coupled to the waveguide remote from the first waveguide device, the second waveguide device having a first input arm and a second input arm, the first input arm being coupled to the data transmitter and the second input arm being coupled to the sensing signal transmitter so that the data signal and the sensing signal are transmitted to the second waveguide device for launching into the waveguide.

15. The link of claim 14 wherein the second waveguide device is coupled to the waveguide by an output arm which receives both the data signal and sensing signal from the second waveguide device.

16. The link of claim 12 wherein the first waveguide device is coupled to the waveguide by an input arm so that both the sensing signal and data signal are transmitted through the input arm to the first waveguide device.

17. The link of claim 14 wherein the first waveguide device comprises a first wavelength multiplexing/demultiplexing (WDM) coupler having the input arm and the first and second output arms.

18. The link of claim 17 wherein the second waveguide device comprises a second wavelength multiplexing/demultiplexing (WDM) coupler having the first input arm, the second input arm and the output arm.

19. The link of any one of claims 12 to 18 wherein the waveguide comprises an optical fibre.

20. The link of claim 18 wherein the second output arm of the first WDM coupler is connected to a reflector to reflect the sensing signal back into the waveguide through the WDM coupler, and the second input arm of the

second WDM coupler is connected to an ancillary coupler, the ancillary coupler having first and second ancillary input arms, the first ancillary input arm being connected to the sensing signal transmitter and the second ancillary input arm being connected to the sensing signal detector so that the sensing signal reflected back from the reflector passes through the first WDM coupler, and through the second WDM coupler to the second input arm, through the ancillary coupler to the second ancillary arm and then to the sensing signal detector.

21. A method for securing live-fibres against tampering and tapping-off of data in optical fibre communication links, including:

providing a sensing system light source operating at a wavelength different to the communications system light source;

providing a wavelength multiplexing waveguide light splitter or coupler (single or multi moded) which efficiently combines the sensing and communications signals into one waveguide;

providing a silica waveguide (single or multi moded) for receiving light from the wavelength multiplexing waveguide light splitter or coupler, the silica waveguide being capable of transmitting the sensing and communications signals;

providing a wavelength demultiplexing waveguide light splitter or coupler (single or multi moded) which splits or separates the sensing and communications signals into two output waveguide ports while minimising optical power losses to both the communications and sensing signals; and

detecting the sensing signal to determine if any tampering with the silica waveguide has taken place.

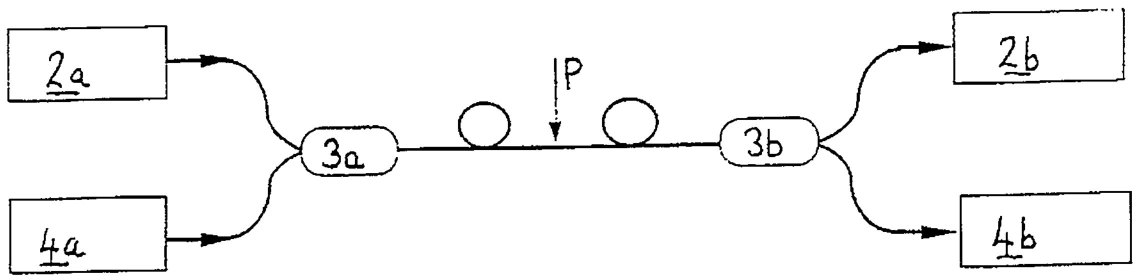


Figure 1

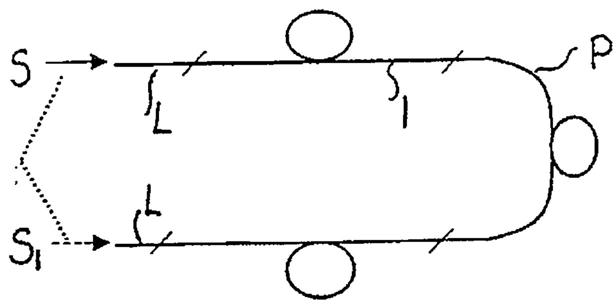
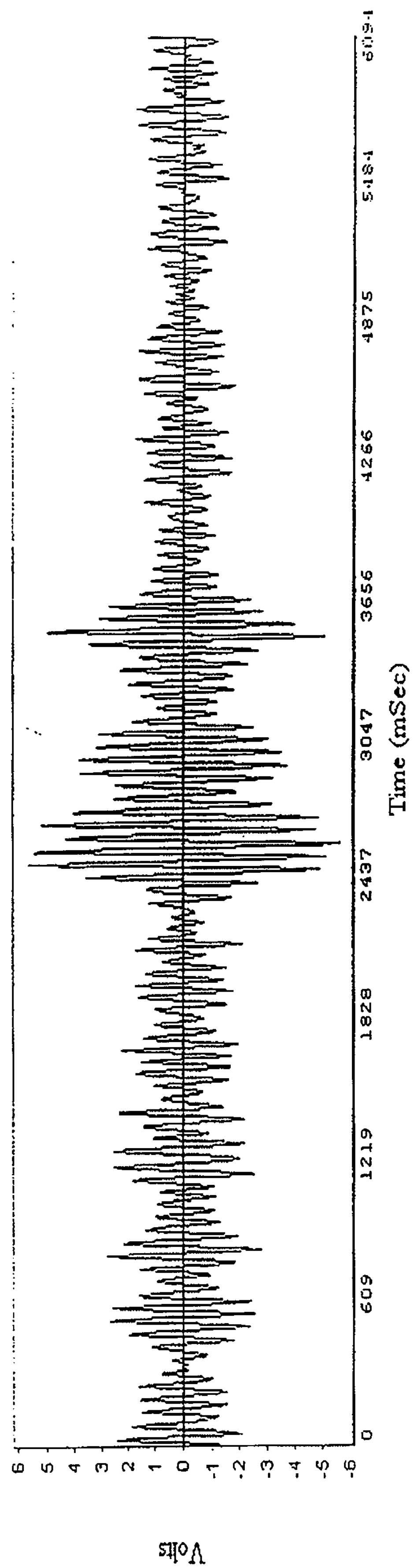


Figure 3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5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
609
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1828
2437
3047
3656
4266
4875
5484
6094
Time (mSec)

Figure 2a

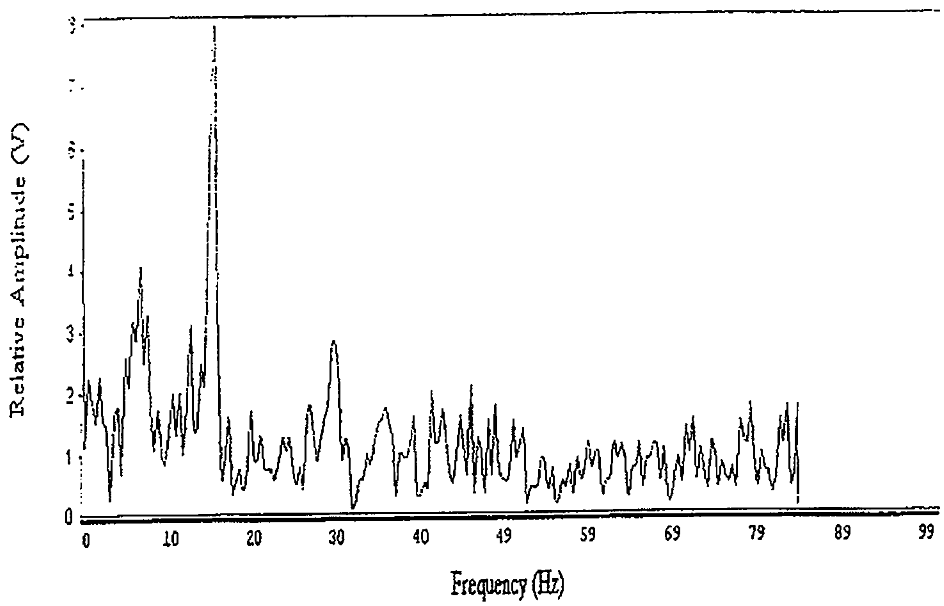


Figure 2b

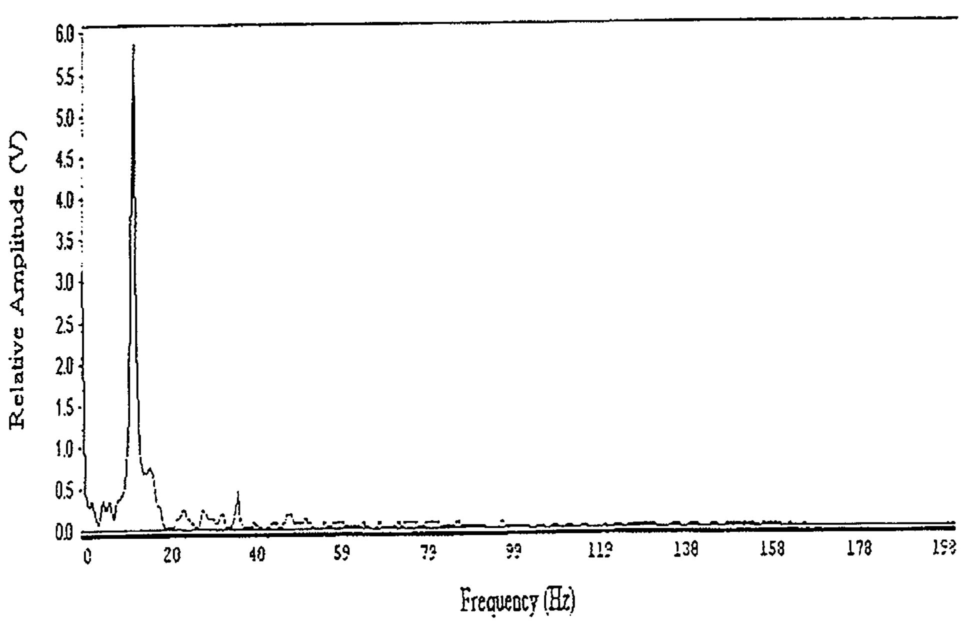


Figure 2d

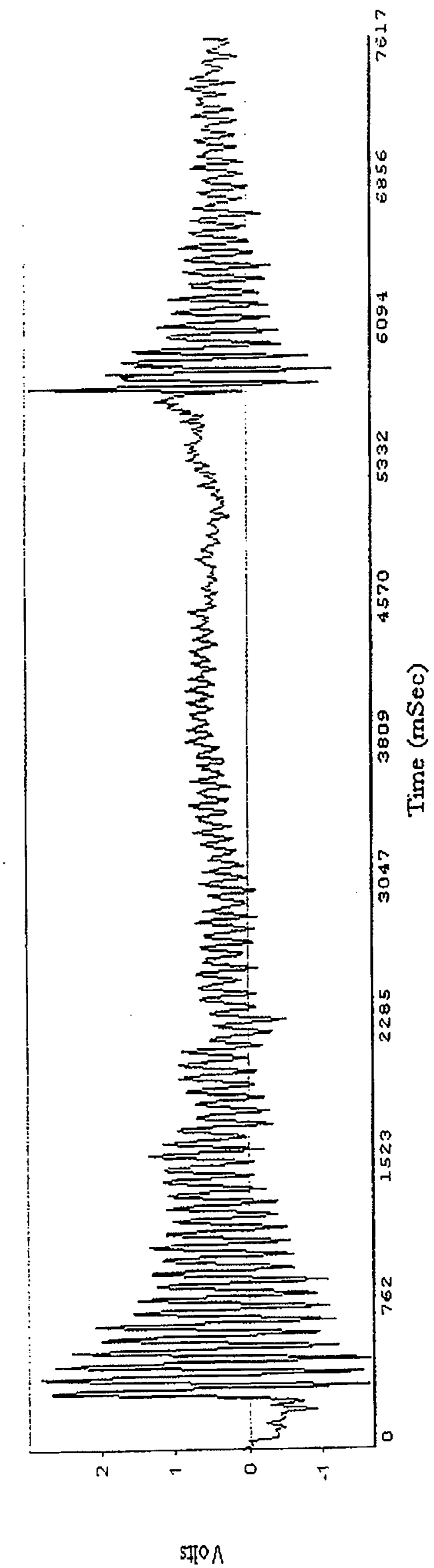

0
762
1523
2285
3047
3809
4570
5332
6094
6856
7617
Time (mSec)
2
1
0
-1
Volts

Figure 2c

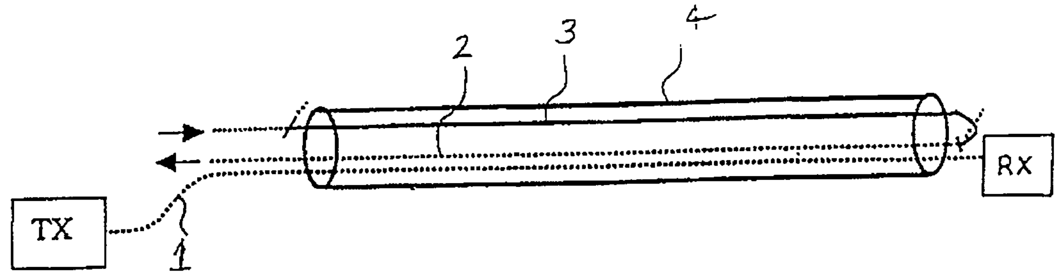


Figure 4

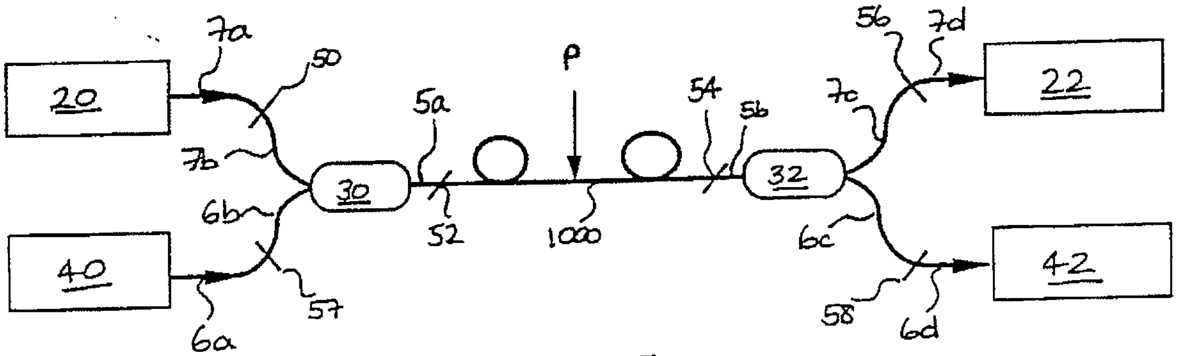


Figure 5

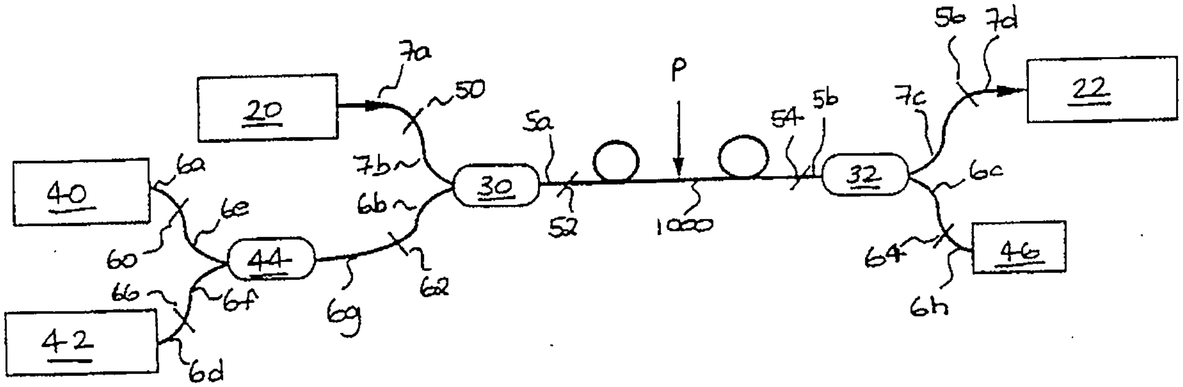


Figure 6

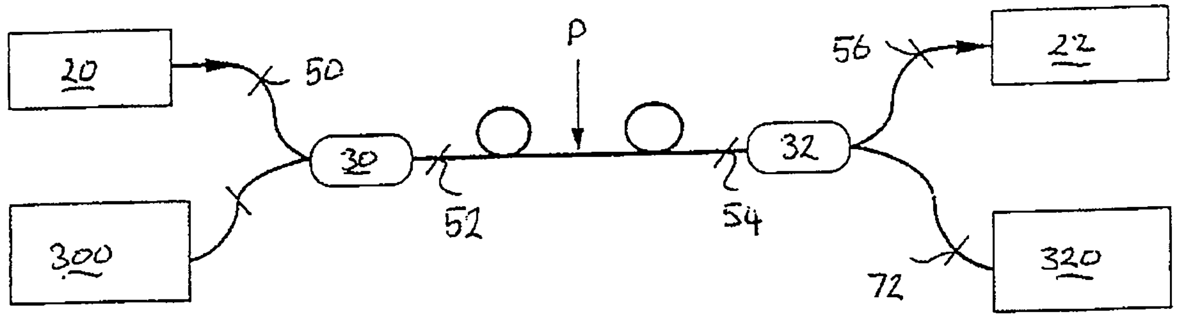


Figure 7

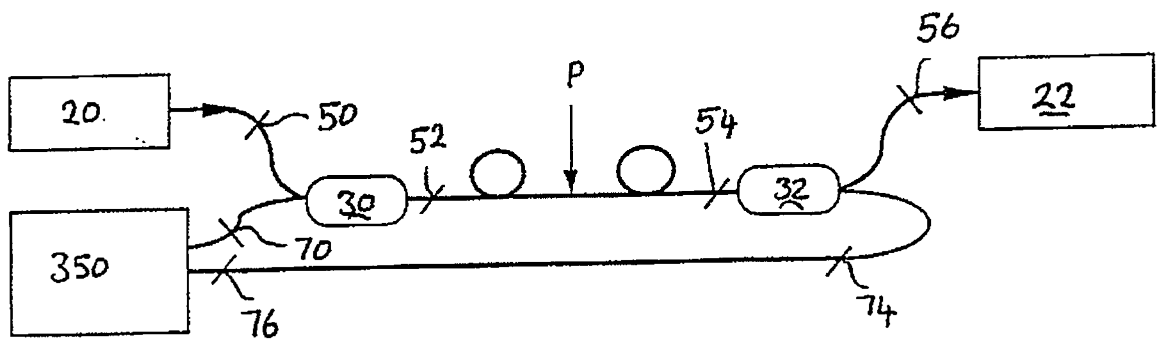


Figure 8

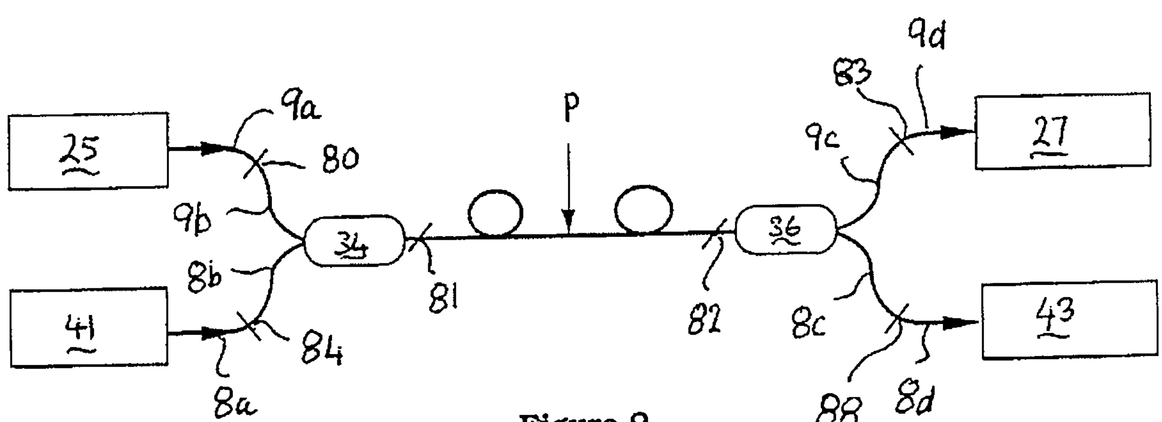


Figure 9

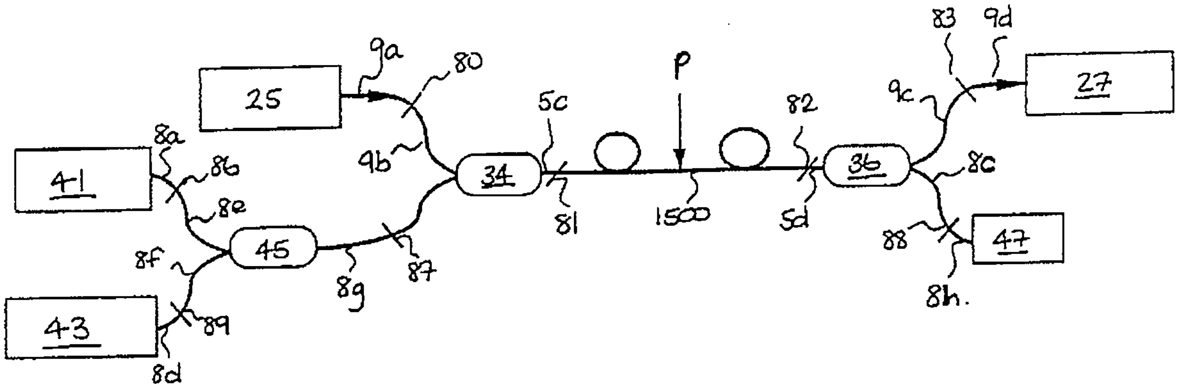


Figure 10

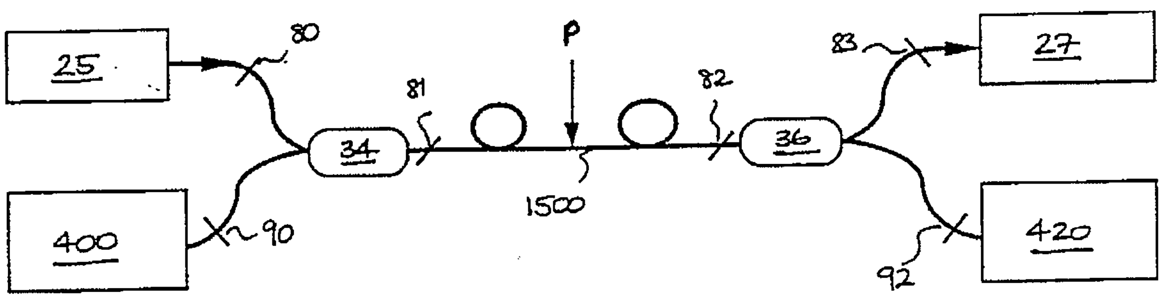


Figure 11

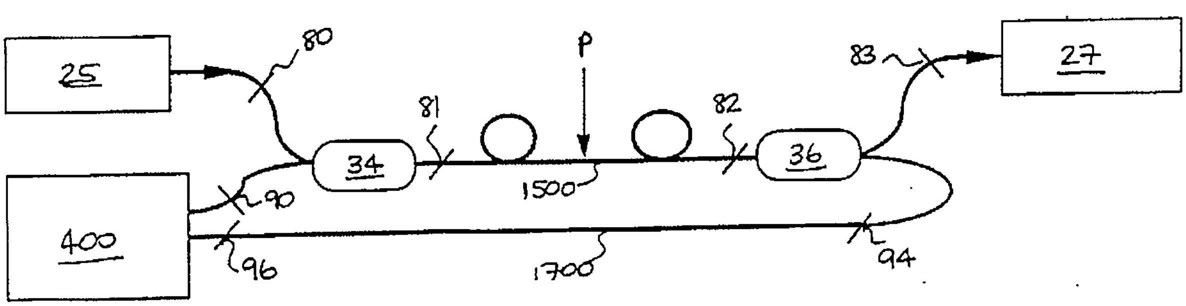
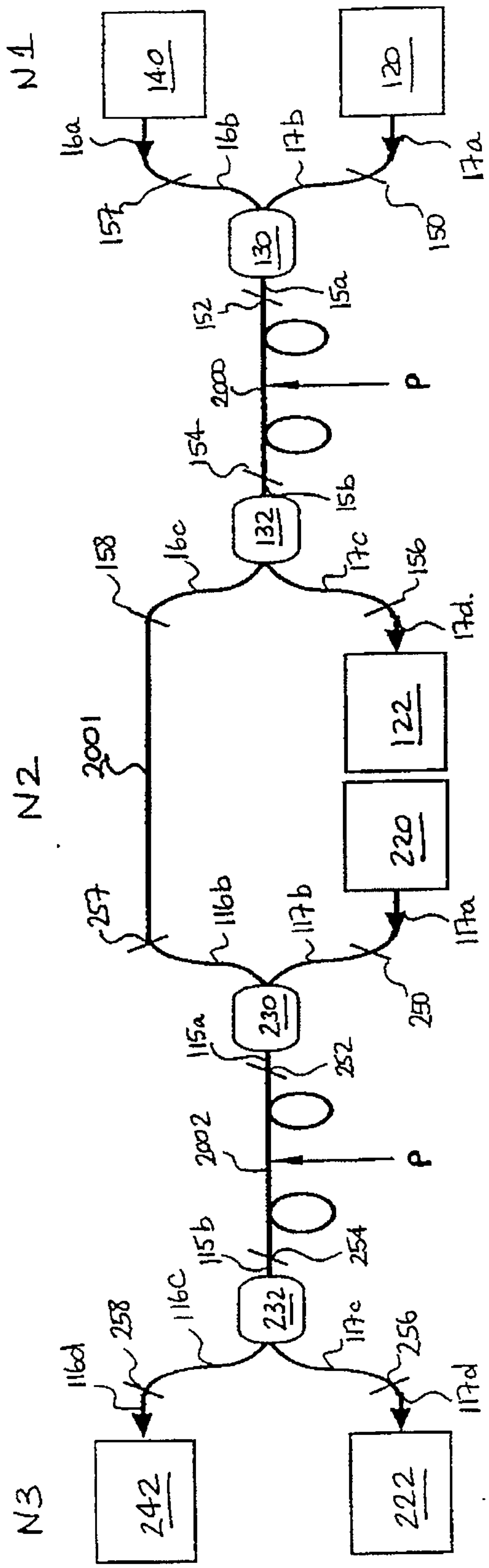


Figure 12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120
16a
16b
17b
17a
157
130
150
152
15a
2000
P
154
15b
132
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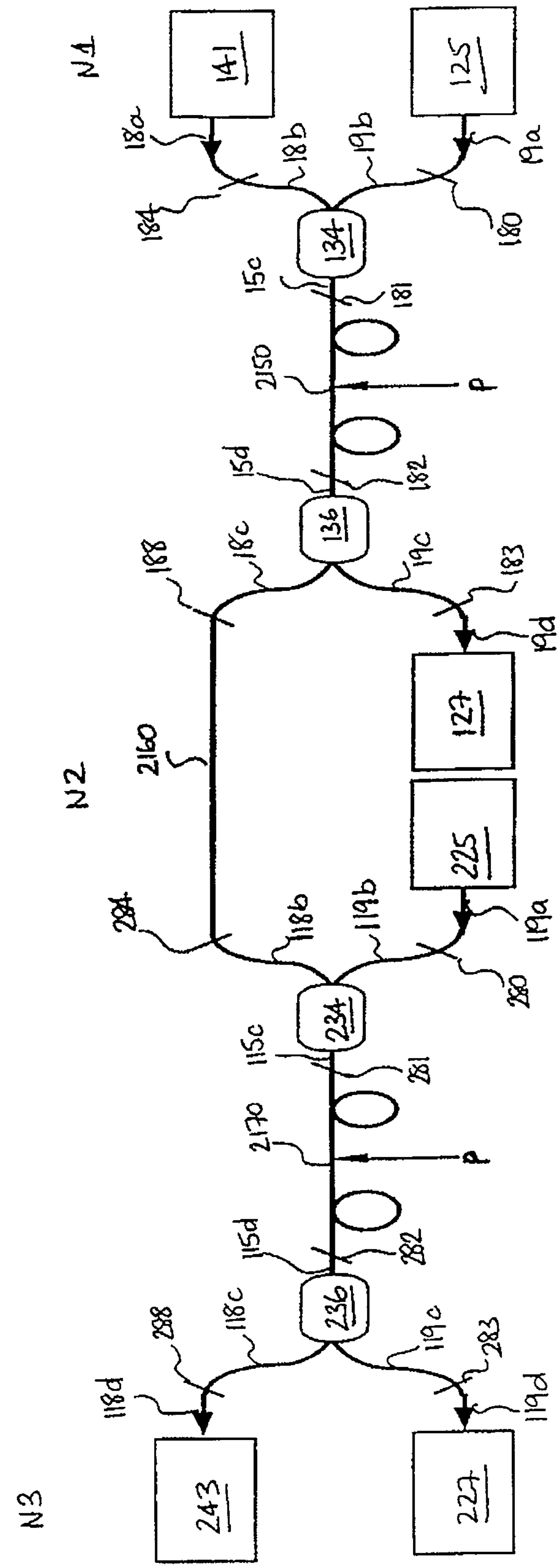
16c
17c
156
17d.
122
2001
N2
220
257
116b
117b
117a
230
250
115a
252
2002
P
115b
254
232
116C
117c
258
256
116d
117d
N3
242
222

Figure 13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18b
19b
19a
184
180
134
15c
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2150
P
15d
182
136
188
18c
19c
183
19d
127
2160
N2
225
284
118b
119b
119a
280
234
115c
281
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P
115d
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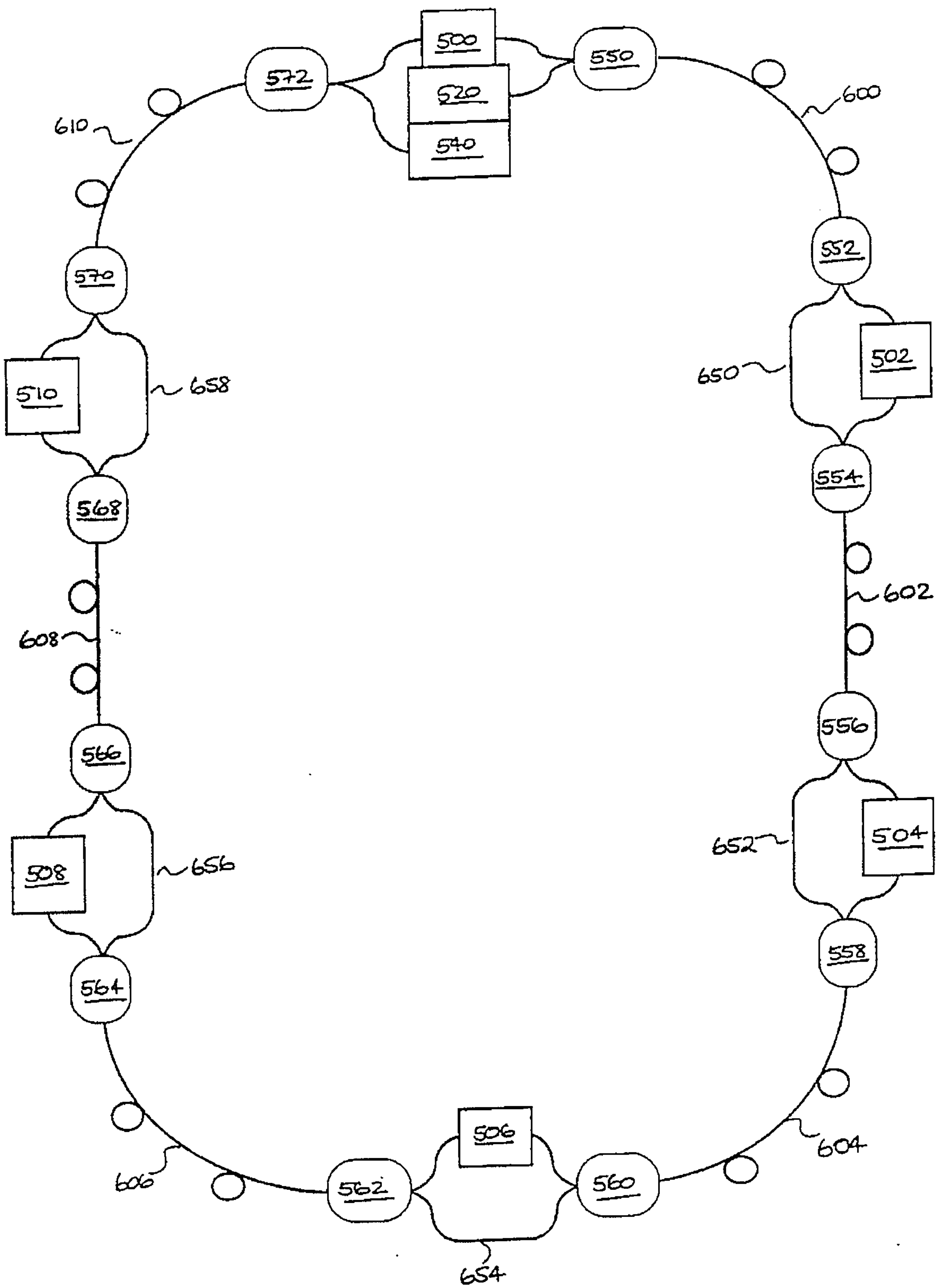
236
288
118c
119c
283
118d
119d
243
227
N3

Figure 14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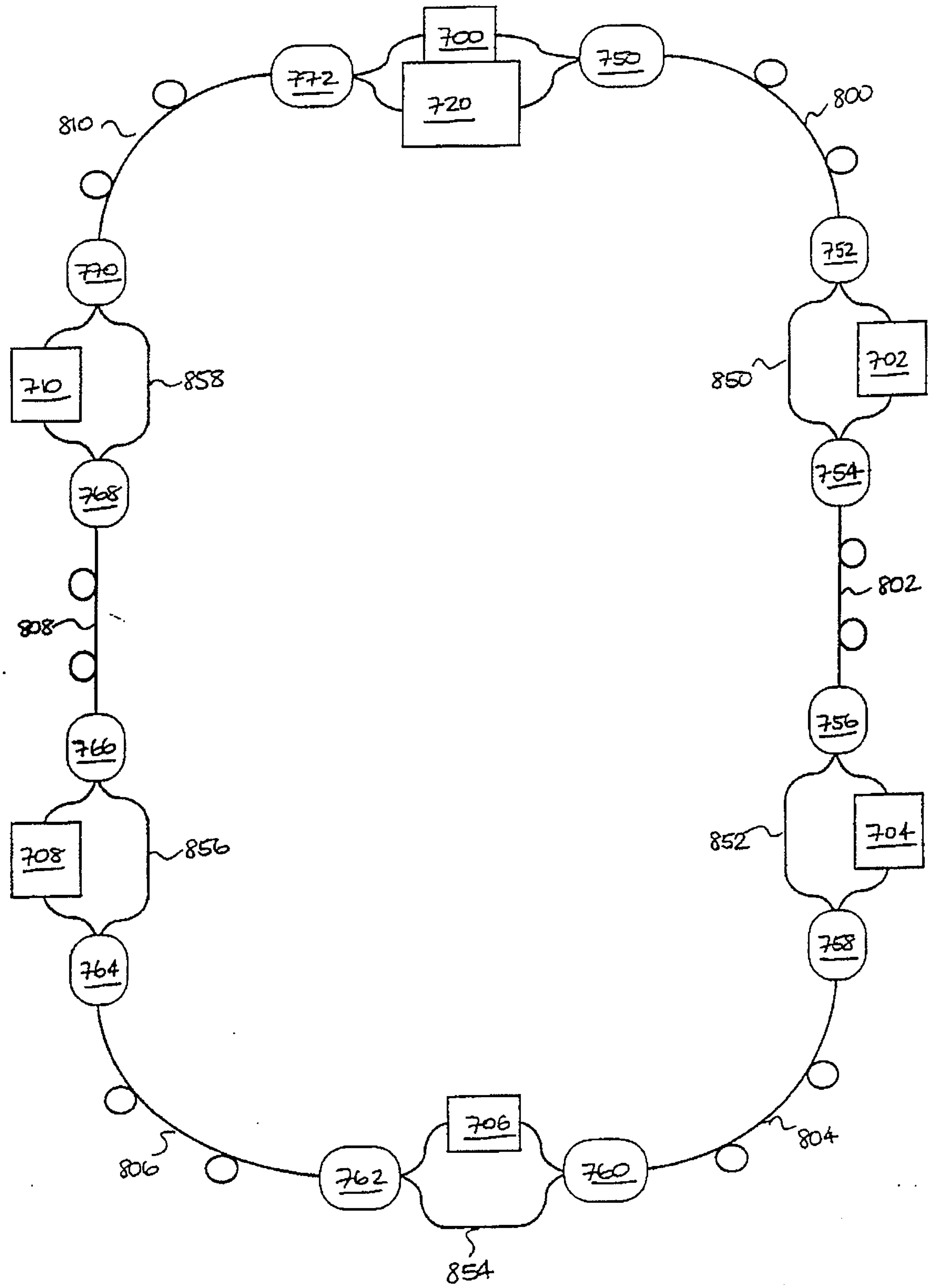
654

Figure 15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770
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754
768
802
808
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704
708
856
758
764
706
804
806
762
760
854

Figure 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00382

A.	CLASSIFICATION OF SUBJECT MATTER
Int. Cl. 7:	H04B 10/12, H04J 14/02, H04L 1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04J, H04B, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 4427514 A (SIEMANS AG) 2 August 1996 The whole document	1-21
X Y	US 4965856 A (SWANIC) 23 October 1990 The whole document	1-21 7
Y	US 5455698 A (UDD) 3 October 1995 Column 15 line 9 - column 18 line 21	7

☐ Further documents are listed in the continuation of Box C ☐ See patent family annex

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Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2000	05 JUL 2000
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